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MINUTES OF PROCEEDINGS

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXIV.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1895-96.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

14 January, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Member.

WILLIAM JOHN CUDWORTH. | JOHN CHARLES JOHNSON.

And that the following Candidates had been admitted as

Students.

THOMAS ROBERT LAMB ABBOTT.
GERALD CARLYLE ALLINGHAM.
REGINALD BOUCHER.
ALFRED WILLIAM BUMPUS.
GEORGE STEPHEN COLEMAN.
FRANCIS EDWARD DAVIES.
CHARLES DRESSER.
CHRISTOPHER GEORGE DUDFIELD.
ANTHONY ETHERIDGE.
WILLIAM HARKER FLETCHER.
CHARLES SAMUEL HAINWORTH.
ERNEST WILMOT HAINWORTH.
WILLIAM EDWARD JACKSON.
SUNDARAM ARUMBUR JUGADISA AIYAR, B.A.
FRANCIS EDWARD KENYON.
JOHN FORSTER LIST.
MALCOLM LITTLE.
ROBERT GORDON MACKAY.
HAROLD GREENWOOD MARRIAN.
SYDNEY WILLIAM MOORE, B.A.
ALFRED MARK MORGAN.
WILLIAM GERALD MORRIS.
ALGERNON DUNBAR PACK-BERESFORD.
GEOFFREY HOPE PEARSON.
OSCAR CHARLES RAPHAEL.
THEODORE RICH.
CHARLES HENRY RICHARDS.
GEORGE WILLIAM WIDNALL.

The Candidates balloted for and duly elected were: as

Member.

JOHN FREDERICK ROBINSON.

Associate Members.

HERBERT BARRINGER.
ROBERT ALEXANDER JOHN BERRY.
JOHN BURDON.
ALEXANDER ERNEST CARROLL, Stud. Inst. C.E.
CHARLES ARTHUR EDWARDES.
FREDERIK OLE ERICHSEN.
JOSÉ XAVIER FERREIRA.
GEORGE TERTIUS GLOVER, Stud. Inst. C.E.
EDGAR HENRY QUIXANO HENRIQUES, Stud. Inst. C.E.

Associate Members—continued.

JOHN KEMP-WELCH.
RICHARD KNIGHTS.
KERR LOCHHEAD, B.Sc., Stud.Inst. C.E.
JOSEPH GOMES NETO.
EDWARD RICHARD ERNEST ROTTER, Stud. Inst. C.E.
HENRY VAUGHAN CRAWFURTH SMITH.
CHARLES NIGEL STEWART.
THOMAS ROBERT JOHN WARD.
WALTER STANLEY WHITWORTH.
GERALD BOURCHIER SHERARD WREY, Stud. Inst. C.E.

Associate.

GEORGE STEYMAN GIBB.

(Paper No. 2884.)

"The Sanitary Works of Buenos Ayres: Sewerage, Drainage and Water-Supply."

By the Hon. RICHARD CLERE PARSONS, M.A., M. Inst. C.E.

THE city of Buenos Ayres is situated on the western shore of the Rio de la Plata, at a place where its breadth exceeds 30 miles. The ground here rises to a height of about 60 feet above the water-level, forming a bank near to which the river flows, whilst above and below there exist marshes extending for a considerable distance between the high ground and the river. This spot was selected as the site for the city evidently for this reason, and hence probably the origin of its name, indicating good air, the situation being free from the exhalations from the swamps, which were experienced above and below it. An additional reason for the selection of the site was that the small river El Riachuelo de las Matanzas, which flows into the Rio de la Plata at this point, formed a convenient natural harbour for small vessels, the only one, until recently, the city possessed.

The general plan of Buenos Ayres, Fig. 1, Plate 1, shows the several districts into which it was necessary to divide the city when laying out the works to be described. The principal part of the city, A, is bounded on the south and west by a steep bank, or "barranca," which was doubtless at one time washed by the waters of the Rio de la Plata. The flat low-lying district, B, of Boca and Barracas, is submerged for the greater part when sudden floods occur in the Riachuelo, or during exceptionally high tides in the Rio de la Plata. The slope of the barranca and a narrow strip of land between its foot and the river are included in the area C, which is liable in places to be flooded during exceptionally high tides. The area D, forming the basin of a small stream now

intercepted by the drainage works, is somewhat less elevated than the area, and forms a separate district. The land reclaimed from the Rio de la Plata by the recently constructed Port Works, the water-supply and drainage of which, although not yet carried out, have been provided for in the design of the works, is shown at E. On the south side of the Riachuelo, there is a populous district, F, known as Barracas al Sur, but this is not comprehended in the area of the works.

Over the larger part of its area the city is built with great regularity, the streets crossing one another at right angles, and at distances apart of 150 Spanish varas, a recognised measure of distance, known as the "cuadra," or "square." The area enclosed between four streets or squares, containing 22,500 square varas, is also a recognised measure, known as the "manzana."[1] The streets are, as a rule, somewhat narrow, the width between the houses in the older or central part of the town being about 31 feet, and in the suburbs about 45 feet; the widths of the footpaths being 5 feet and 7 feet respectively.

The datum used in the construction of the works was 100 feet below the pavement of the porch of the cathedral, which may be regarded as the mean level of district A, the highest point of which is 20 feet above that level. The level of the ground varies in district B between 45 feet and 53 feet, in district C between 52 feet and 93 feet, and in district D between 53 feet and 83 feet above datum. The district E is practically level and about 53 feet above datum. The mean high- and low-water levels of the river are respectively 42 feet and 39 feet above datum, but the water-level is liable to considerable fluctuation, and has been observed to fall to 31 feet and to rise to 51 feet 10 inches above datum. Such extreme variations are, however, rare, and the ordinary range may be taken to be between 35 feet and 47 feet above datum.

The annual rainfall in the province of Buenos Ayres varies considerably, and has been known to be as low as 23 inches and as high as 46 inches, the average for ten consecutive years being $33\frac{1}{2}$ inches. Although the daily rainfall in Buenos Ayres is recorded at the University, the observations do not give the rates at which the rain falls during short periods. It is, however, well known that during sudden storms, which frequently occur, 4 inches of rain have fallen within one hour; and in 1884, when

[1] The value in English measure of a "square" is about 142 yards, and that of a manzana slightly over 4 acres.

a serious flood occurred, 9 inches fell in twenty-four hours. It is also recorded that during a storm of extreme violence 5·71 inches of rain fell in four consecutive hours.

The city of Buenos Ayres is built entirely upon alluvial deposits, and no rock occurs on the southern shore of the Rio de la Plata within 250 miles. At the level of the river along the foreshore, and at a varying depth beneath the city, an indurated greyish clay deposit, locally termed "tosca," is found, whilst above this exists a hard clay of a reddish colour, termed "tierra pampeana,"[1] which rises nearly to the surface of the ground throughout the town. Embedded in both of these deposits are found the fossilized remains of antediluvian animals, such as megatheria, in a perfect state of preservation. Both the "tosca" and the "tierra pampeana" are compact, free from faults, and eminently suitable for supporting the foundations of large and massive buildings.

The hottest months of the year are December, January, and February, when the temperature in the shade, in the garden of the Observatory, has been known to rise as high as 103·1° F., and a temperature of 95° F. has frequently been recorded. On the other hand, the coldest months are as a rule June, July, and August, when slight frosts are experienced, due generally to intense radiation, as the atmosphere in winter is usually clear and free from fog. As a result, thin ice is found on sheltered ponds, which however soon disappears under the action of the sun's rays.

The country bordering the Rio de la Plata is subject to violent wind storms, which generally blow from the south-west off the Pampa, or open country, and are known in the Republic as "pamperos." The maximum velocity of these winds recorded at

---

[1] The chemical composition of this deposit is shown by the following analysis by Dr. Arrarta ("El clima y las condiciones higienicas de Buenos Aires" 1889):—

	Per Cent.
Water and volatile materials	1·860
Silica	82·325
Alumina	9·975
Oxide of iron	3·253
Carbonate of calcium	1·122
Oxide of magnesium	0·984
Phosphoric acid, sulphuric acid	..
Chlorine, potash, soda, &c.	0·481
	100·000

the Observatory in Buenos Ayres is 100 miles per hour. Destructive cyclones also occasionally occur, but these are local in their action, and no reliable records exist in regard to their force.

In the year 1870, the late Mr. J. F. La Trobe Bateman, F.R.S., Past-President Inst. C.E., was consulted by the Government of the Province of Buenos Ayres as to the construction of a port for that capital; also with reference to the extension of the water-supply, and with regard to a system of drainage. The city was at that time in possession of an inadequate supply of water, and no efficient provision existed for dealing with the heavy rains. The sewage was also for the most part disposed of by means of cesspools, which were rapidly impregnating the subsoil with fæcal matter, and as a result the city was becoming more and more subject to epidemics of cholera and yellow fever, the latter of which is prevalent in the neighbouring Republic of Brazil. At the period referred to, a serious outbreak of yellow fever occurred, which carried off a considerable portion of the population, and had the effect of hastening the initiation of the sanitary improvement works about to be described.

The water-supply which then existed had been designed by the late Mr. John Coghlan, M. Inst. C.E., under whose direction the works were executed. The water was drawn from the Rio de la Plata at a point immediately above the city, and after being passed through sand-filters, was raised by pumping-engines to a service-tank for distribution through cast-iron mains, laid in the principal streets of the central portion of the city. The maximum daily supply which these works were capable of affording was 1,500,000 gallons. As this amount was inadequate for the requirements of the city, it was supplemented either by rain water stored in tanks beneath the ground, locally termed "algibes," or by water taken from the river, and distributed unfiltered to the poorer classes by means of water-carts.

The scheme which Mr. Bateman was called upon to devise was therefore fourfold, and consisted of the construction of a port, the introduction of a complete water-supply, the removal of surface water due to heavy rains, and the sewerage of the city. The designs of these several works are intimately connected with one another; but they will be described as far as possible in the order in which they were executed. As the construction of the harbour has passed into other hands, it is only necessary to state that the works have been carried out in the same position as that advocated by Mr. Bateman, the only essential difference between his

design and that adopted, being the introduction of lock-gates, with the object of maintaining the water in the docks at a nearly constant level.

Preliminary Investigations.

Water-supply.—Before the source from which the city was to be supplied was decided upon, samples of water, taken from the Rio de la Plata at the point from which the existing supply was derived, and also at a point about 3½ miles above the city, where, owing to circumstances, it appeared advantageous that the new intake should be constructed, were submitted to Dr. Frankland for analysis. The results are shown in the following Table, together with those of similar tests made upon Thames water supplied to London, and Loch Katrine water supplied to Glasgow:—

Results of Analyses, expressed in Parts per 100,000.

	Buenos Ayres.		London, Thames Water.	Glasgow, Loch Katrine Water.
	Existing Supply.	New Supply.		
Total solid impurity	15·8	10·24	30·94	3·00
Organic carbon	..	..	0·399	0·161
„ nitrogen	..	..	0·048	0·011
Ammonia	0·003	0·002	0·001	0·001
Nitrogen as nitrates and nitrites	0·000	0·000	0·346	0·000
Total combined nitrogen	..	..	0·395	0·012
Previous sewage manure contamination	0·000	0·000	3·150	0·000
Chlorine	2·10	1·82	1·89	0·91
Temporary hardness	2·44	2·31	..	0·00
Permanent „	2·43	2·56	..	0·30
Total „	4·87	4·87	17·30	0·30
Mineral suspended matter	2·10	2·36	traces	0·00
Organic „ „	0·20	0·20	traces	0·00
Total „ „	2·30	2·56	traces	0·00

The water of the Rio de la Plata is extremely turbid, especially after heavy rains have fallen over its catchment-area. The suspended matter consists of a finely divided alluvial clay and sand, of which a large portion is deposited, when allowed to settle for some hours; but the water still exhibits an opalescent appearance which it retains in some degree permanently. Numerous experiments have been carried out by Professor Kyle of Buenos Ayres and others, with a view to ascertain whether, by the addition of chemicals or by the use of any special filtering medium, perfectly clear water could be obtained. It was found that the addition

of either chloride of calcium, sulphate or chloride of alumina, or sulphate of iron, caused the minute particles to subside, and when the water thus treated was passed through a sand filter, it became perfectly clear. It was found also that an animal-charcoal filter, or a Chamberland porcelain filter was capable of clarifying the water. The results of numerous experiments, however, showed that, in order to provide an adequate supply of drinking-water to the city, at a reasonable expense, fine-sand filters were the most satisfactory; and although after passing through such a medium the water remains slightly turbid, it is not found to be injurious to health. The water is distinctly alkaline, and has a most destructive effect upon wrought-iron or steel.

Having ascertained that the water of the Rio de la Plata, when filtered, was in every way suitable for the domestic supply of the city, Mr. Bateman presented a Report to the Improvements Commission in the year 1871, in which he explained in detail what he considered would be an adequate supply of water for the city, and the works which would be necessary to introduce it. As the census returns were imperfect, careful investigations were made as to the number of persons residing in that portion of the city which it was proposed to sewer and supply with water, and it was decided that the works in the first instance should be constructed for a population of 200,000, and that a much larger population should be anticipated at no distant date. Basing his calculations upon the consumption of water in English towns which were equipped with efficient sanitary systems, and allowing an additional quantity on account of the higher temperature of Buenos Ayres, Mr. Bateman considered that a consumption of 40 gallons per head per day of the population should be provided for; and further, that it should be anticipated that the population would more than double itself in twenty years. It was therefore determined that the ultimate capacity of the works should be sufficient to deliver 16,000,000 gallons of water per twenty-four hours for use throughout the city; and, further, as the consumption was more intermittent than in most towns, that the storage capacity of the service-reservoir, and also the distributing mains, should admit of water being delivered at a rate considerably in excess of the average daily consumption. Only those parts of the works which could not be easily duplicated were constructed in the first instance for the full supply, the remainder being of only sufficient capacity to supply 8,000,000 gallons per twenty-four hours.

Sewerage.—In the year 1870, the house-drainage was disposed of

by unlined cesspools. When these became full, the contents were in some instances, especially in the houses of the wealthier classes, removed by means of atmospheric carts. In the smaller houses a new cesspool was sunk in close proximity to the original one, and the overflow conducted into it. This process was frequently repeated several times, and as many as eleven cesspools have been known to exist beneath a single house. Under these circumstances, and in view of the abundant supply of water which it was proposed to introduce into the city, it was decided to recommend the adoption of a complete water-carriage system of sewerage.

In view also of the high temperature which is experienced at certain periods of the year, the inclination of the sewers throughout was arranged so that sewage entering them at a point furthest from the outfall should be discharged within twelve hours from the time at which it entered. The system of sewerage was to be completed, and the houses connected thereto, simultaneously with the introduction of the water-supply, as in the event of this not taking place, the cesspools would become overcharged and the sanitary condition of the city would be imperilled. It was accordingly proposed to adopt a system similar to that in operation at that time for the discharge of the Metropolitan sewage into the River Thames, viz., to store the sewage in reservoirs during the flow of the tide, and, as soon as the ebb commenced, to open the penstocks and allow it to flow into the river. Before deciding to adopt this principle, a careful series of experiments was made with floats dropped into the river at the point where it was proposed to place the outfall, to ascertain the laws regulating the course and speed of the currents. These floats were started at various states of the tide, but the experiments were directed especially to ascertaining what, under the most adverse circumstances of both tide and wind, was the greatest distance the sewage could be carried up the river above the point at which it was discharged. The positions of the floats were periodically noted day and night, after they were started, by means of cross bearings, and their paths plotted. These experiments showed that the currents in the Rio de la Plata were affected more by the action of the wind than by tidal disturbances. If therefore the sewage was discharged every twelve hours, as in the case of London, when the ebb commenced, the current in the Rio de la Plata would frequently be flowing up instead of down, and the sewage be carried in the opposite direction to that intended. It was consequently decided that the discharge should be continuous, and at a point considerably below

that first suggested, so that under no possible combination of tide and wind could the sewage be washed back to contaminate the water-supply or prejudice in any other way the health of the city. The position of the outfall was therefore fixed at a point somewhat south of the town of Quilmes, and at a distance of about 12 miles below the city. When this point was selected the question of irrigating a large area of ground with the sewage of the city was discussed, but as yet no steps in this direction have been taken, although the conduit leading to the outfall has been carried along a line suitable for irrigation works should they be constructed at any future time.

Previously to the construction of the works, the large quantities of water which fell during heavy rains found their way to the river along the streets of the city, which were lowered in many cases as much as 6 feet below the pavements on either side, to enable them to convey this water without flooding the adjacent houses. It frequently happened that during sudden downpours of rain the water in the streets attained a depth of several feet, and cases were not uncommon of horses and carriages being swept along and damaged by these torrents. The works to be described have completely prevented the recurrence of these floods, and have correspondingly increased the value of property in the city.

The Water-Supply.

Intake-Tower.—The intake-tower, Figs. 2 and 3, Plate 1, from which the entire supply of water for the city is drawn, is situated at the point marked G, Fig. 1. The reasons for selecting this point were that the foreshore, which dries for a distance of 1,000 yards from the bank of the river, dipped suddenly into deeper water there than for some distance above or below. A staging of piles was first erected at the site of the tower, and upon it a pile-driver was placed capable of travelling in a circle of 25 feet radius—equal to that of the circular cofferdam it was proposed to construct. Piles, 12 inches square and dressed to the radius, were next driven close side by side, until their ends entered the hard "tosca," which lay at a depth of 10 feet below the bed of the river. The water was then pumped out, and it was found that, with the exception of two small leaks, the cofferdam thus constructed was satisfactory.

In order to secure reliable foundations upon which to construct the walls of the tower, a circular brick shaft of 9 feet 10 inches internal diameter, with walls 1 foot 7½ inches thick, was sunk to

a depth of 14 feet below the bed of the river, surrounded by twelve octagonal cylinders, measuring 5 feet 10 inches between opposite sides, also of brickwork 1 foot 7½ inches thick, which were sunk to a depth of 10 feet below the river-bed. An inner shaft, 8 feet in diameter, was then sunk inside the circular cylinder to a level of 6 feet 6 inches below datum, or 34 feet below the bed of the river. This shaft was carried up above the bed of the river by a brick cylinder, 8 feet 9 inches in diameter and 2 feet thick, to the level of the highest floods, and four sluices were inserted in the sides to govern the admission of the water. Around this shaft a tower was built of concrete, faced with brick, its foundation being the twelve octagonal cylinders. The tower is square in plan, the angles being formed with granite quoins. In the lower part, opposite to the four sluices in the inner shaft, are four openings for the admission of water, fitted with strong iron gratings to prevent the entry of timber or other floating material. The walls of the tower are continued about 16 feet above the top of the inner shaft, the space between them being roofed over to form a valve-chamber, in which the gear for working the sluice-valves is placed. The walls of this upper portion are built of concrete blocks, with granite quoins and cornice. A shaft, also 8 feet in diameter, was sunk at the point marked H, Fig. 1, to a depth of 6 feet below datum, on the line of the tunnel close to the bank of the river, at a distance of 1 mile from the intake-shaft.

Tunnel.—It was decided that the tunnel connecting these two shafts should be driven at a level of 1 foot 6 inches above datum at the intake-shaft, with a fall of 18 inches in its length to the land-shaft. Four intermediate shafts were sunk on the line selected for the tunnel. From the appearance of the excavation in the two shafts, it was thought that comparatively little water would be met with in driving the tunnel, but this proved not to be the case, and great difficulties occurred from this cause as the work proceeded. The pumping-power provided by the contractors was inadequate to cope with the water, and an attempt to utilize air-pressure to reduce the influx proved a failure, owing to the defective arrangements adopted. Eventually, however, by increasing the pumping-power at the several shafts, the tunnel was completed.

Considerable difficulties were also encountered in lining the tunnel, but were eventually overcome by laying a 12-inch drain-pipe in the floor, discharging into the sumps at each shaft. The bricks for the lining were cemented into sections of four

bricks each, and in this way centering was dispensed with. Much difficulty was experienced in jointing the segmental sections of brick to obtain a water-tight lining. This arose chiefly from the want of the necessary air-pressure appliances, the cement being washed out of the joints in many cases before it had time to set.

Although the ordinary water of the Rio de la Plata is extremely turbid, that which found its way into the tunnel during construction was perfectly clear and much harder than the water of the river. This seems to demonstrate that the water in the subsoil through which the tunnel was pierced did not filter in from the river, but was subterranean water which had travelled for a long distance underground in the direction of the Rio de la Plata. This conclusion is supported by the results of observations made by Dr. Arrata,[1] who found, by means of a series of wells sunk in the "tosca," that the subsoil water in the vicinity of Buenos Ayres travelled continuously underground in a definite direction. Throughout the area of the Argentine Republic over the greater portion of which there exists a fair average rainfall, few rivers exist, and the inference is that the water finds its way to the sea by subterranean flow.

The shaft on the bank of the river having been completed, an engine- and boiler-house were erected over it; and a vertical-spindle centrifugal pump, actuated by a horizontal high-pressure engine, was provided for the purpose of laying dry the tunnel whenever cleansing became necessary. Owing to the difficulties and delays which occurred in driving this tunnel, the conduit for conveying water from the last-mentioned shaft to the pumping-station at I, Fig. 1, was completed some time previously. The experience gained in sinking the shafts for this tunnel showed that a large quantity of subsoil water would be met with, and the depth below the surface of the ground at which it was driven was therefore reduced as far as possible. This caused a difference of 22 feet between the level of the tunnel under the river and that under the land, and rendered necessary the erection of the pump for laying dry the tunnel under the river. This tunnel, which commences at H at a level of 21·25 feet above datum, was driven from fourteen shafts with an inclination of 1 in 6,320; and both it and the shaft under the river are capable of conveying 20,000,000 gallons of water per twenty-four hours. Ten of the fourteen shafts remain open, and the entrances

[1] El clima y las condiciones hygienicas de Buenos Aires, 1889.

have been raised above the level of the highest floods; they serve for ventilation, as well as for the cleansing of the tunnel when necessary.

Recoleta Establishment.—The tunnel terminates at what is known as the Recoleta Establishment, Fig. 4, Plate 1, where the water of the Rio de la Plata is cleansed from the suspended alluvial matter which it contains. It is raised from the conduit and delivered into settling-ponds by the engines in the pumping-station No. 2, the lift being about 20 feet when the river is at its mean level. From these settling-ponds the water flows on to the filters, through which it descends into clear-water reservoirs constructed beneath them; thence it is raised at the pumping-station No. 1 into the service-reservoir, the lift varying between 116 feet and 162 feet, according to the section of the reservoir into which it is pumped.

Intake pumping-station.—In the pumping-station No. 2 are installed two horizontal condensing-engines, each actuating a set of three-throw pumps capable of delivering 8,000,000 gallons of water per twenty-four hours. This engine-house, originally constructed in 1874, is being duplicated, and the engines which are being erected, Figs. 19 and 20, consist of two pairs, each capable of raising 10,500,000 gallons per twenty-four hours. They are compound direct-acting, the high- and low-pressure cylinders being each vertically over the pumps with which they are connected. The crosshead of each piston-rod is connected direct to the pump crosshead by two rods between which the cranks on the fly-wheel shaft revolve and the connecting-rods oscillate. The admission- and outlet-valves are independent of one another, and are of the double-beat type actuated by cams. The pumps, which are similar to those attached to the older engines, are of a somewhat peculiar construction; both the inlet- and outlet-valves being circular and of indiarubber. They are placed in the top covers, being thus easily accessible, and are of such ample area that loss due to the friction of the water through them is avoided. The boilers for these engines are three in number, of the cylindrical single-flue multitubular type, designed for a working pressure of 120 lbs. per square inch. The gases, after leaving the central flue, pass to the front, along the sides, and thence underneath the back of the boilers; and before escaping up the chimney pass through a Green feed-water heater.

Settling-ponds.—The settling-ponds, Figs. 5 and 6, Plate 1, are three in number, each covering an area of about 90,000 square feet, the highest water-level being 53 feet above datum. Each is inter-

sected with cross-walls forming continuous channels along which the water passes before it flows on to the filters. The distance which the water travels before it escapes from each settling-pond is 3,100 feet. The three ponds are worked in series of either two or three, and are each designed to deal with 4,000,000 gallons in twenty-four hours. During the time which the water remains in the settling-pond, the alluvial matter in suspension is gradually deposited at the bottom of the channel, and the clearest water is continuously drawn from the surface by means of adjustable weirs at the extremity. As a rule, each settling-pond is in service for six weeks, the water being decanted by means of the weirs on to the filters as far as the relative heights will admit, about 3 feet, the remainder being allowed to run to waste into the river. The settling-pond is then thoroughly cleansed from deposit by means of a small quantity of water retained for the purpose at the upper end, and allowed to escape by raising a sluice. With this water the floor and sides of the pond are washed, the contents being allowed to escape through the wash-out apertures at its lower end.

The settling-ponds are formed partly in cutting and partly in embankment, the slopes being lined, as shown in Figs. 5, with pressed bricks set on edge in mortar, and laid upon a double layer of hand-made bricks also set in mortar. The total capacity of the settling-ponds when all are in operation is 12,000,000 gallons per day, and although one may be thrown out of service for cleansing, the maximum daily supply is not necessarily reduced; as the velocity of the water through the two remaining in service may be accelerated, as this only has the effect of throwing a small additional quantity of alluvial matter upon the filters.

Filters.—The filters, Figs. 7, 8, 9, 10 and 11, are three in number, each 250 feet square and capable of passing 4,000,000 gallons per twenty-four hours; but allowing for the cleansing of the sand, an average discharge of 10,000,000 gallons per twenty-four hours from the three filters can be maintained. The water is conveyed from the settling-ponds through a 36-inch pipe to a valve-well from which it can be distributed to either of the three filters. It is admitted to them through open channels 3 feet 6 inches wide by 3 feet 6 inches deep, which pass round three sides of each filter and also have branches along the division walls. In each filter twenty-four lateral openings in the channels give access to the filter-beds, and these can be closed when necessary by iron doors so that any compartment can be isolated for cleansing. The filtration of the

water downward is at a rate of 6 inches per hour, the water being maintained as a rule about 3 feet deep over the sand.

The filtering material consists of a layer, 2 feet thick, of fine sand resting on successive layers, 6 inches thick, of coarser sand, gravel and broken stone, in which are buried the outlet-drains, consisting of bricks laid with open joints, forming rectangular channels 6 inches by $4\frac{1}{2}$ inches, placed transversely to the filter and 9 feet 9 inches apart. These channels fall into a longitudinal channel 12 inches square, placed along the foot of one wall of each compartment of the filters, and deliver into wells built against the side walls, two being provided for each compartment. The water finally leaves the filter through an orifice in a horizontal plate laid in the floor of these wells.

The rate of filtration is automatically regulated by a paraboloidal module working in the horizontal plate, Fig. 11, and constructed of the proper form to discharge at a constant rate with variable head. The module is worked by a float placed inside the well, and compensates for the varying rate of filtration, which would result either from increased head on the filters, or variations in the condition of the sand. The depth of water over the sand, although generally maintained at 3 feet, is capable of variation between 3 feet 6 inches and 6 inches, falling to the latter level when it is necessary to draw upon the storage of the settling-ponds. The head needed for filtering through the sand varies from a fraction of an inch, with perfectly clean sand, to as much as 2 feet when the sand has been in use for some time, and has become choked by the fine silt contained in the water; the water in the well, after filtration, will therefore stand 5 feet higher when the filter is full and the sand clean than when the filter is nearly empty and the sand dirty; consequently, the module is constructed so as to discharge equal quantities with this range of head. To reduce the length of the module, gearing is introduced by which its range is reduced to one-fourth that of the float. There is a further adjustment obtained by changing the relative positions of the float-wheel and the pinion, which enables the rate of filtration to be varied between 6 inches and $3\frac{3}{4}$ inches per hour.

Pure-water Reservoirs.—Owing to the low level at which a reliable foundation was met with at the site of the filters, and further as storage-reservoirs for filtered water were needed, it was decided to construct the filters upon arches raised some distance above the solid ground, the space thus obtained beneath them being utilized as the storage-reservoir for filtered water, Figs. 8 and 9. These reservoirs extend over the whole area of the filters,

and are 10 feet deep, their capacity being 10,000,000 gallons. The filters are supported upon continuous walls 9 feet 9 inches apart, connected by semicircular arches upon which the filtering material is laid, the outlet channels of the filters being in the spandrils formed between them. At the central point, where the three filters approach each other, a well is formed, reaching to a depth of 11 feet below the floor of the reservoirs. The filtered water is admitted into this well from each reservoir by means of sluice-valves, and flows from thence to the pumping-station No. 1 by a tunnel passing beneath the floor of one of the reservoirs. A similar well communicates with a drainage-tunnel discharging into the pump-well of the inlet station, so that on emptying one of the reservoirs, the water in the lower portion of it can, if necessary, be pumped back into the settling-ponds and filtered a second time.

For some years these filters remained exposed to the dust-storms and the tropical sun during the hot season, the former adding to the clogging, and the latter speedily producing a growth of green slime upon the surface of the sand, which had the effect of preventing the filtration proceeding at the necessary rate. The filters were accordingly covered to exclude all light. The roofs, Figs. 8 and 9, consist of steel trussed principals, of about 78 feet span, spaced 9 feet 8 inches apart, and resting upon lattice girders supported by cast-iron columns, which stand upon the walls of the filters. The external covering is composed of corrugated galvanized-iron, secured firmly to the principals, and also to the angle-bars, which connect each principal with the next. Along the entire length of each ridge, skylights, glazed with rolled glass, are provided, under the eaves of which are ventilators to allow of the escape of the heated air. The lower member of each principal is arranged so that it can be adjusted in length when in place, in order to preserve an even line along the roofs. As the heat of the sun is intense during the hot season, it was necessary to fix a ceiling of non-conducting material under the roofs to prevent the water from being heated during filtration. Between this ceiling and the corrugated iron roof, a current of air is set up, which effectually prevents the heat of the sun from affecting the water. Wire-wove roofing material was selected for the construction of this ceiling, being attached to light rafters supported upon the tie-bars of the roofs. Under the ridge of each roof is a series of balanced doors in the ceiling, made of the same material, to admit light whenever the sand of the filter requires cleaning. When this process is completed and the filter charged, they

are again closed, and the filtration continues in almost absolute darkness.

Surrounding these filters is a handsome brick wall, Fig. 8, with central porticos in which are inserted at short intervals cast-iron gratings for the purpose of allowing a current of air to pass over the water during filtration. In order to resist the wind-pressure of the hurricanes which sweep over the country, the columns supporting the roofs are arranged in double rows, and are securely braced together from the top of one to the base of the next. The walls surrounding the filters are therefore not subjected to any lateral force. Additional filters are in course of construction, similar in principle to those already built, but modified in detail to omit the reservoirs for the storage of filtered water.

Pumping-Stations.—The main or No. 1 pumping-station, Figs. 4, Plate 1, Figs. 21 and 22, Plate 2, in which are the engines and pumps for raising the filtered water into the service-reservoir after leaving the filters, consists of two separate engine-houses and sets of machinery. The first engine-house and the machinery it contains were erected in the year 1874, and consist of two pairs of non-compound beam engines, each pair actuating two pumps from the ends of the beams opposite to those to which the piston-rods are attached. The valves for the admission of steam to the cylinder, and for the exhaust, are of the double-beat type actuated by means of cams, and the condensers are on the injection principle. There are eight boilers for supplying the steam, of the Lancashire type and designed to carry a steam-pressure of 60 lbs. per square inch. Each pair of these engines is capable of raising 8,000,000 gallons of water from the clear-water reservoirs into the service-reservoir in twenty-four hours.

In the year 1890 a second pumping-station was erected immediately adjoining the main pumping-station to accommodate two pairs of engines and pumps. These engines and pumps also raise the water after passing through the filters and deliver it into the service-reservoirs, but can be worked independently of those in the older station. In view of the high price of fuel in Buenos Ayres, which consists entirely of English coal at about 35*s.* per ton, every effort was made to introduce all the most recent improvements into these engines. Compound engines of the beam type were selected. The pumps are double acting, and are worked off the opposite end of the beams to that to which the piston-rods are attached. The fly-wheel of each pair of engines is placed between them, the cranks being set at right angles. The admission- and

exhaust-valves are of the double-beat type, and are actuated by cams from the crank-shaft.

The pumps are of a construction introduced with the object of obtaining an adequate area of passage for the water through the valves, to reduce the friction as far as possible and also to render the valves accessible. This has been accomplished, Fig. 23, Plate 2, by placing the inlet- and outlet-valves in separate chambers. Surface-condensers have been adopted, and through these is carried the entire water-supply pumped by the engines. The steam is supplied from eight double-flued multitubular boilers, and the gases, after passing along the sides and under surface, are carried through a feed-water heater before escaping to the chimney-shaft, which is 150 feet in height. Each pair is capable of delivering 10,500,000 gallons of water into the service-reservoir in twenty-four hours.

The total pumping-power in this station is represented by the lift of 37,000,000 gallons to a height of 158 feet including friction, in twenty-four hours. In case of repairs being necessary, each pair of engines is arranged so that by uncoupling any one connecting-rod the other engine of the pair can still be worked independently. The engines and boilers are constructed for a working steam-pressure of 120 lbs. per square inch. The whole of the machinery in both the main and intake pumping-stations was manufactured by Messrs. James Watt & Co., and has worked satisfactorily.

The pump-mains, which convey the 16,000,000 gallons of water from the older engine-house to the service-reservoir, consist of three cast-iron pipes 24 inches in diameter, and those for conveying the 21,000,000 gallons from the newer engines to the same reservoir consist of two cast-iron mains 33 inches in diameter. The length of each of these mains is 7,315 feet, and ample provision has been made so that any one of them can be thrown out of service if necessary, should a burst occur or repairs be required.

Service-Reservoir.—The city of Buenos Ayres being nearly flat no eminence of any importance is available upon which to construct a masonry or embanked service-reservoir for the distribution of the water throughout the city. A sufficient elevation for this purpose does not exist within a radius of many miles, and it was determined, therefore, that the reservoir required for this purpose should be constructed within the city on the most elevated site available, and that it should be raised above the surface of the ground. The point selected was in a district of the city which was rapidly coming into favour for residential purposes, especially

by the wealthier classes, and the Argentine Government stipulated that the exterior of the service-reservoir should be handsome, and in keeping with the buildings both public and private which were rapidly rising in the vicinity. It was also determined that the reservoir should be capable of containing one day's supply of water for the city, estimated at 16,000,000 gallons; and further that the ground floor of the building should be capable of being used for some public purpose.

At the time when the architectural design of this building and the materials which were to be used in its construction were to be determined upon, the Argentine Government had already expended a large sum upon the works, most of which had been laid out upon the construction of sewers and other works underground, which had left no visible record of the magnitude of the undertaking. The Government desired, therefore, that the structure should serve as a monument of the works, and wished, further, that native materials should enter into its construction to as large an extent as possible. The Author's firm was instructed to prepare designs which would as far as possible carry these views into effect. At this period marble quarries had been opened at Azul, which, by rail, is about 250 miles from Buenos Ayres, and it was suggested that this material should be used largely for the decoration of the building. Granite also, of excellent quality, was procurable in the Republic of Uruguay, on the other side of the Rio de la Plata, and its employment was also considered. It was found, however, when suitable designs were prepared, and estimates made, that not only would the use of these materials entail heavy expenditure, but would also cause considerable delay in the execution of the work. The Author's firm accordingly suggested that the walls of the building should be constructed of native-pressed bricks, and that the whole of the external decoration should be composed of terra cotta imported from Europe, as thereby a considerable saving would be possible.

The architectural style of the building is French renaissance, and the enrichments are elaborate. The walls were designed of the required strength to support not only a small portion of the weight of the reservoir, but also to be capable of resisting the force of the pamperos. It was also necessary that the four walls of this building, which measures inside 296 feet square, and is of a height of 66 feet to the top of the parapet, should be capable of resisting this wind-pressure without any support from each other except at the four corners. The architectural design of the structure was therefore governed to a large

extent by the necessity of effecting this object, and massive towers were placed not only at the four corners of the building, but also in the centre of each side. Substantial buttresses were also worked into the design at stated intervals between the central and corner towers, both inside and out, which impart the required strength to the walls at those places.

The bases of the walls are laid upon a bed of Portland-cement concrete, which is continued over the entire area of the building, as shown in Fig. 12, Plate 1, and rests upon the solid "tierra pampeana" at a depth of about 10 feet below the surface. The footings are extended for a considerable distance on either side of the line of the walls to distribute the weight, and thus, as far as possible, avoid any danger of a settlement occurring. The walls are constructed throughout of pressed bricks of local manufacture, and carefully selected, so that the hardest and best burnt might be used in the lower part of the structure, and the remainder in the upper part, where there was less weight to be supported. These were set in Portland-cement mortar, varying in strength between 2 to 1 and 3 to 1. During the building of the walls the necessary recesses and toothings were left, into which the terra-cotta blocks were subsequently fitted and set in cement. In this way the brickwork of the walls was entirely covered with a layer of terra cotta.

The reservoir consists of three tiers of tanks, each tier being divided into four separate compartments. The twelve tanks are approximately of the same dimensions, viz., 135 feet square and 13 feet in depth, and each contains on an average 1,324,000 gallons of water when filled to the working-level, and the twelve, when all are in service at one time, contain 15,888,000 gallons. In addition to the twelve principal tanks, a fire-tank is placed on the top of the central tower, on the northern side, 25 feet long, 20 feet broad, and 13 feet deep, containing 40,000 gallons of water when filled. The lower tanks, Fig. 12, in each of the four sets, which are similar in every respect, are supported on cast-iron columns, of which there are forty-five to each tank, the foundations for each consisting of a brick pillar surmounted by a granite bedstone built upon the layer of concrete. The foot of this brick pillar is widened and constructed upon a slab of stronger concrete, which distributes the weight in such a manner that the pressure upon the ground does not exceed 2 tons per square foot, and that between the slab and the lower layer does not exceed 5 tons per square foot. The piers are constructed of specially-burnt bricks, and are so proportioned that the pressure they trans-

mit to the concrete slabs does not exceed 7 tons per square foot. Upon the top of each pier are the granite bedstones which transmit a pressure of 10 tons per square foot to the bricks, and the cast-iron bases of the columns transmit 15 tons per square foot to the granite. Each of the forty-five columns is composed of four smaller flanged columns 11 inches in internal diameter and $\frac{7}{8}$ inch thick, connected together in two places in their length by means of cast-iron intermediate plates. The greatest precautions were taken to ensure the lengths of the flanged columns being exactly equal so that the same weight may be supported by each. Connecting the tops of the columns to each other, and also those at the sides to the surrounding walls, is a network of plate-girders 20 feet in length and 3 feet in depth, with flanges at the top and bottom 12 inches in breadth. Each of the spaces between these main girders is spanned by two lighter girders, with their ends resting upon their lower flanges. The entire area occupied by the columns is therefore divided into a network having spaces each 6 feet 8 inches by 20 feet. Across the platform of girders thus formed are placed rolled joists 8 inches in depth, their flanges being 4 inches in breadth. Upon these joists are laid the plates forming the floor of the tank of the lowest tier. This is formed of wrought-iron plates $\frac{1}{2}$ inch thick, 4 feet wide and 12 feet long, planed on the edges and connected together on the under side by cover-plates 5 inches wide and $\frac{1}{2}$ inch thick, and on the upper side by T-bars 5 inches by 4 inches by $\frac{1}{2}$ inch. The sides of the tanks are also constructed of $\frac{1}{2}$-inch plates, and are connected to the floor and to one another at the corners with L-bars $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch. The jointing of the side-plates is similar to that used for the floor. The sides of the tanks are supported against the internal pressure of the water at intervals of 4 feet apart by means of five wrought-iron stays connecting the T-bar cover-plates on the floor to those on the sides.

As the tanks would be exposed to a range of temperature of about 70° F., it was necessary to provide for a corresponding periodic expansion and contraction. In addition to these periodic disturbances the danger of displacement due to contraction in any part not being equal to that due to expansion, or *vice versâ*, was considerable, and as a result a continuous motion might occur between the several portions of the structure which, unless provided for, would lead to disastrous results. These several disturbances were met in the following manner. The floor of each tank, being practically a continuous plate of wrought-iron 135 feet square, the expansion and contraction would naturally take place equally in every direction. On the other hand, the ground into

which the foundations of the columns are sunk would not be affected appreciably in this way by change of temperature, consequently the tops of the columns furthest from the centre of the floor of the tank would be most displaced by any expansion and those nearer to it in a correspondingly smaller degree. It was therefore determined to fix the centre of the tank relatively to the walls of the surrounding building, and to allow it to expand outwards freely in every direction from this point. A circle was then traced on the floor of the tank beyond which the expansion would be more than any column should be subjected to, and within this radius the twelve columns are securely tied together diagonally in both directions with ties reaching from the cap of one column to the base of the next. The centre of each of the four tanks on the first tier is by this means rendered immovable horizontally by any change of temperature. Beyond the circle it was necessary to introduce a provision for allowing the floor of the tank to expand relatively to the girders supporting it. The floor of the tank is a continuous surface of considerable strength and rigidity, and it was considered advisable that the caps of the columns outside the circle should not be allowed to slip upon the floor of the tank when any expansion took place. The ends of the girders resting upon the tops of the columns are therefore arranged with expansion rockers, Fig. 13, so as to be free to expand in a longitudinal direction, thus preventing any tendency of the caps to slip upon the tank floor. The ends of the girders also resting upon the inner and outer walls of the building are all supported upon expansion rockers so that no perceptible horizontal force can be applied to the walls. The columns situated beyond the circle are subject to displacement from the vertical due to the expansion of the floor of the tank. It was therefore necessary that both the bases and caps of the columns should be fitted with ball-and-socket joints as shown in Fig. 14. The ratio between the radii of curvature of these joints and the heights of the columns is such that although the surfaces may become rusted, due to moisture entering between them, their functions will not be impaired.

In order to support the second tier of tanks, the columns sustaining those just described are continued upwards through the lower tanks, and are surrounded with square wrought-iron casings of a length equal to the depth of the tanks and riveted to the floor. These casings are 3 feet 10 inches square, and sufficient space is allowed inside them for the execution of any repairs that may be necessary.

The forty-five columns supporting each tank on the second tier each consist of four separate flanged columns united at intervals with cross-plates in a similar manner to those supporting the lower tank, but lighter in section, being $9\frac{1}{4}$ inches in internal diameter and $\frac{3}{4}$ inch in thickness. Upon the tops of these columns is provided a network of girders and rolled joists similar to those supporting the first tier of tanks. Similar provisions are adopted for neutralizing the expansion of the girders supporting the floor of this tank to those introduced on the first tier, both on the tops of the columns and also on the walls surrounding the tanks. No rocking-caps and bases were introduced into the columns above the floor of the first tier of tanks, as the temperature of the floors of the three tiers would remain approximately the same at all times.

The tank on the top tier is supported by columns similar to those described for the second tier but lighter in section, being $7\frac{1}{2}$ inches in internal diameter and $\frac{11}{16}$ inch in thickness. Upon the tops of these columns also rests a network of girders and rolled joists, similar to those supporting the tanks on the first and second tiers. Under the ends of these girders, both where they rest upon the columns and also upon the surrounding walls, are provided rockers exactly similar to those on the first and second tiers.

The mains which convey the water from the pumping-station terminate opposite the central tower on the northern side, and are there connected to three vertical pipes, 24 inches in diameter, which carry the water upwards to the top of the building. At the level of each tier of tanks connections are made to these vertical pipes, and by a complete system of valves each tank of each tier can be thrown in or out of service as required independently of the others. Each connecting pipe is also provided with a reflux valve, so that in the event of a burst occurring in the mains the water in the tanks is prevented from escaping. Overflows of ample dimensions, of the Appold type, Fig. 15, are provided in each tank to avoid any danger of their overflowing, and further, washout plugs are fixed, as cleaning is necessary to remove the deposit resulting from the suspended matter in the water. On each floor, in each of the central towers, are constructed chambers containing the valves for regulating the flow of water into the tanks and its delivery to the several sections of the city; these are reached by means of spiral staircases from the ground-floor.

It was necessary in order to protect the upper tier of tanks from the action of the sun, that the whole building should be roofed, and further, that the central and corner towers should be sur-

mounted by domes to complete the architectural design. It became at once apparent when the designs for these roofs were considered that special precautions must be adopted to resist the force of the storms. Although the walls of the building between the central and corner towers are made sufficiently massive to resist the greatest wind-pressure which had been recorded, they are not of sufficient strength to withstand the additional force due to this wind-pressure impinging upon the high-pitched roofs surmounting them. It was therefore determined to make the roofs depend for their stability upon the iron structure supporting the tanks. Columns were erected on the floor of the tank of the upper tier vertically over each column which supports it. These columns are securely braced with inclined ties attached to the T-bars on the floor of the tank, and the roof, which consists of thirteen ridges and the corresponding valleys, each of 20 feet span, is supported upon them. The steep-pitched roofs surrounding the building springing from the gutter behind the parapet are of the Mansard type, and are secured to the main portion of the roof, but only stepped upon the surrounding walls, Fig. 13, Plate 1. The entire wind-pressure upon the roofs is therefore transmitted into the floor of the upper tank, and in order to convey this to the ground diagonal ties are introduced between the columns on each side of the central alleys on each tier. These ties prevent the displacement of the floor of the tank on the two sides, and on the other two sides next the walls provision is made by which the force is transmitted into the walls only in the direction of their length, in which direction they have ample strength to resist it. This is effected by the addition of flanges to the pins of those rockers of the top tier which rest upon the walls, to make them capable of resisting lateral force.

The framework of the dome roofs, both of the central and corner towers, is of wrought-iron, and is connected to the brickwork by means of holding-down bolts which are carried 13 feet into it to obtain the required stability, and the whole is securely braced to resist wind-pressure. The roofs are slated with green slates from the quarries at Sedan, France. Surrounding the site upon which the structure stands is a massive iron railing, and the entrance gates are of handsome design.

The terra cotta for the decoration of the walls of the building was contracted for by Messrs. Doulton & Co., who sublet the glazed ware to the Burmantofts Company of Leeds. The terra cotta material consisted of about 170,000 blocks, exclusive of about 130,000 glazed bricks, necessitating not only a vast number of

drawings but also a corresponding number of moulds. The whole was erected in place without any serious difficulty.

The contract for the supply and erection of the ironwork was placed in the hands of the Société anonyme de Marcinelle et Couillet, Belgium, with whom were associated the Société anonyme de Sclessin, Liége, and also the late Mr. Aug. Lecoq of Hal. This work, the weight of material in which amounted to about 13,000 tons, was executed in every way satisfactorily, and both the testing of the tanks, and the constant service during the past two years has proved that the designs were correct, and testified to the care with which the work was constructed.

On the 27th of October, 1894, a serious earthquake occurred in the Argentine Republic and was felt severely in Buenos Ayres, but, although it is stated that waves were produced in the tanks 6 inches in height, no damage whatever was caused to any part of the structure. Disturbances of this nature were quite unknown in the locality at the time the reservoir was designed.

City Water-Mains.—The outlet mains, where they leave the service-reservoir, are so arranged that, by means of a complete system of valves, any one of the three tiers of tanks can be connected with the distributing pipes in any district of the city. It has, however, been specially arranged that the city shall be divided into three zones, which its conformation naturally indicates, and the three tiers of tanks connected with the pipes in such a way as to supply each according to their relative levels. The outlet pipes from the service-reservoirs consist of one 36-inch pipe from the first tier, one 33-inch and two 24-inch pipes from the second tier, and one 36-inch pipe from the top tier. A pipe, 30 inches in diameter, is also laid across the basement of the reservoir to connect the inlet- and outlet-pipes, so that, in the event of exceptional pressure being required, the pumping-engines can be made to deliver direct into the mains, the principal tanks being shut off, and the fire tank acting as an equalizer of the pressure. The several mains, after leaving the service-reservoir, are carried along the most convenient streets to make connection with the service systems throughout the city, Fig. 16, Plate 1.

Uniform systems of both distributing- and service-mains, varying in diameter between 30 inches and 2 inches, are used. The primary mains are laid along the streets running north and south, in parallel lines, at intervals of eight squares apart. The secondary mains branch from the primary mains at intervals of four squares apart, and are carried along the streets running east and west. In this way the whole city is divided into blocks, each

having an area of 32 manzanas, or 128 acres. The primary mains vary in diameter between 36 inches and 12 inches, according to their distance from the service-reservoir, but the secondary mains are all 10 inches in diameter for the first two squares, 9 inches for the next three squares and 8 inches for the remaining three squares. Each extremity of the secondary mains is connected with the adjoining primary main, and is capable of being closed at either end with a stop-valve so that the whole of the secondary mains, in lengths of eight squares (about $\frac{3}{4}$ mile), can be isolated. Each secondary main is provided with at least one air-valve and one drain-valve in its length, and similar provisions are made with respect to all the primary mains so that they may be drained and the air allowed to escape.

None of the primary or secondary mains are tapped directly for domestic use or for fire-hydrants, these supplies being taken from a separate system connected by branches with the secondary mains. One system of distributing pipes is shown in Fig. 17, as applied to a block of four manzanas, and is repeated throughout the districts marked A, C and D, Fig. 1. The distributing piping in each block consists of a 5-inch pipe laid between two adjoining secondary mains, from which pipes 4 inches in diameter, reduced to 3 inches when the first hydrant is passed, branch out at the four successive street corners. These pipes encircle the remaining three sides of the manzana, which is thus entirely surrounded, there being a separate service for the supply of the houses on the opposite side of every street.

The hydrants, three in number to each block, are placed one on a 5-inch, one on a 4-inch and one on a 3-inch pipe. Stop-valves are placed at each branch, and drain-valves at the lowest point in each pipe, as well as blow-through valves at each dead end. The arrangement adopted presents great advantages as regards uniformity in the position of valves and hydrants, and the ease with which any pipe can be shut off without depriving the district of water, since an alternative route for the supply is in all cases available.

The double system of distributing pipes enables connections to be made without disturbing the roadway, its extra cost being to a great extent compensated for by the reduced length of service-piping, and also the smaller diameter of the distributing pipes which are required. The pipes are of cast-iron, with turned and bored joints: all special pipes, however, were made with wide sockets for lead joints, and wherever the distance between two special pipes exceeded 50 yards a lead joint was specially introduced into the regular piping. The stop-valves are all double faced, those of

greater diameter than 10 inches being laid on their side and worked with gearing enclosed in valve-chambers constructed under the streets, and sufficiently large to permit the tongue of the valve being removed without disturbing the surface of the road. The air-valves are of the double-ball pattern, 4 inches in diameter for pipes up to 15 inches, and 8 inches for larger pipes. It was necessary to construct these latter of special patterns and to place them as far as possible under the side-walks, as the traffic in the streets is very heavy, and the paving in many of the districts defective.

Where the distance was too great to carry the air-valve to the roadside, it was placed in a chamber constructed immediately alongside the pipe, and covered with a heavy cast-iron frame filled with wooden blocks. In all cases a stop-valve is placed between the pipe and the air-valves. The drain-valves on the main piping are 5 inches in diameter for all sizes of pipe, and those on the distributing piping, as well as the blow-through valves at the dead ends, are 2 inches diameter. The hydrants are of the ball pattern, 2 inches in diameter, the balls being specially made of vulcanite to resist the high temperature to which they are exposed.

In the district marked B, Fig. 1, Plate 1, the comparative irregularity in the arrangement of the streets prevented this system of piping being carried out with absolute uniformity, but the arrangement is based upon the same principle as that described above. A modification, Fig. 18, Plate 1, was, however, introduced into the arrangement of the smaller distributing pipes, which were connected with two of the 5-inch pipes, instead of with one only as elsewhere, the hydrants being all placed on pipes not less than 4 inches in diameter. By this change additional security is afforded against interruption to the supply through the breakage of a 5-inch pipe, the pressure available in the hydrants is slightly increased, and the 3-inch pipe is reduced in diameter to 2 inches. A special arrangement of hydrants supplied by pipes of large diameter is provided along the wharves of the Riachuelo and of the south tidal basin, for the protection of the warehouses and shipping.

Connections to the Houses.—The question as to whether it was preferable to adopt a system of water-supply by meter, or by an annual tax upon the rateable value of the properties supplied, was fully considered. The conclusion arrived at was that, in the interest of the public health, it was desirable that an ample supply of water should be allowed to flow down the sewers, and that if meters were adopted, especially in connection with the houses of the lower classes, a sufficient quantity of water would not be used.

n addition, the primary outlay in the purchase of meters would ave been considerable; and further, the annual repair, owing o the alluvial deposit in the water, would have been so large hat it was preferable to devote this expenditure to defray the ost of the supply of a larger quantity of water, as the source from vhich it is obtained is unlimited. In the service main opposite ach property is fixed a stop-valve from which is carried a lead ipe into each house.

Internal Water-Supply.—The internal water-supply and house-rains, although carried out by the individual proprietors, were equired to be in conformity with by-laws framed by the Improve-nents Commission, and were executed under the inspection of the uthor's firm, for whose approval the plans of all internal works vere required to be submitted. These by-laws were framed to orrespond, as nearly as local circumstances would permit, with hose generally in use in England, and the internal work may be aken as fulfilling all the conditions of modern sanitary require-nents. The water service-pipes inside the houses are of lead hroughout, and the fittings are of types and manufacture anctioned by a public testing-office specially constituted for the urpose.

Sewerage.

Internal House-Drains.—The main internal house-drain, 4 inches n diameter, starts in an inspection chamber, placed as near as ossible to the boundary of the property, into which air is admitted y a 4-inch pipe. Where, as is usually the case, the houses abut irectly on to the street, this pipe terminates in the front wall of he house, at a considerable height above the ground, to prevent any nnoyance from back draught, which is generally further guarded gainst by mica-flap valves. From this chamber, the principal nternal house-drain is laid with a minimum inclination of 1 in 40, r where this cannot be obtained, the sewage is discharged by utomatic flushing-tanks. Ample ventilation is provided on the nain drain, and on all branches where the latter are more than 10 eet in length. The water-closets are of the flush-out type, provided n all cases with automatic flush-tanks of 2 gallons discharge. All ain-water pipes, bath, lavatory, and kitchen waste-pipes, are cut ff from the drain by trapped gullies, and the latter are provided vith grease-traps, placed wherever possible out of doors, and fficiently ventilated. Inspection-chambers or covers are placed t every angle in the principal drain, and the whole internal

drainage-system of each house is cut off from the public sewer by a siphon-trap placed at the junction of the internal and external portions of the drain. Figs. 24 and 25 show a typical average-sized dwelling-house with the drainage as carried out.

External House-Drains.—The external house-drain, or that connecting the property with the public sewer, is in all cases 6 inches in diameter, being thus larger than the house-drain with which it communicates. This arrangement enables a 6-inch siphon-trap to be used on the 4-inch drain, and the increased size materially reduces the chance of obstruction in the trap, and removes the objections which have been raised, more especially in America, to siphon-traps in this position. At the upper end of each external house-drain, and immediately below the siphon-trap, a 4-inch air-pipe is carried up the front of the house to a height of 6 feet above any adjoining roof. These pipes serve to ventilate the public sewer, and at the same time prevent the unsealing of the siphon-traps by the sudden filling of the sewer by heavy rains.

Collecting-Sewers.—To facilitate the arrangement of the collecting-sewers, the city, with the exception of districts B and E, is divided into twenty-nine separate divisions, each of which is drained independently. The sewers in each division converge to the lowest point, where the sewage is admitted into the intercepting sewers through regulating-chambers. The districts into which the whole city is divided are shown on the plan of the intercepting-sewers, Fig. 37, Plate 3, and the sewers in one of the districts are shown in detail in Fig. 26, Plate 3. The size of these districts varies between 82 manzanas and 17 manzanas, or between 328 acres and 68 acres, and are determined by the levels of the ground and by the discharging capacity of the largest sewer employed. The drainage, with the exception of district B, is on the combined system, the collecting-sewers being utilized for the conveyance of both sewage- and rain-water, and their size is therefore determined by the heaviest rainfall which it is necessary to dispose of. This quantity has been assumed throughout the whole of the works to be $1\frac{1}{2}$ inch of rain per hour flowing off the whole area; an allowance which experience has shown to be sufficient, although, as has already been stated, the actual rainfall is frequently largely in excess of this amount. Almost the whole of the rainfall finds its way into the sewers, as in many districts the entire area consists of roofs and paved streets or courtyards, in which there is practically no absorption, but the retarding effect of the almost level ground and

f the horizontal flat roofs of the houses, aided by the storage apacity of the sewers themselves, have the effect of so equalising ne flow as to bring it within the limit already stated.

The larger sewers are of oval section of the form shown in ig. 27, Plate 3, and are constructed of concrete 6 inches to 9 inches hick, composed of one part of Portland cement to six of sand. he inverts are formed of earthenware blocks, and the sides, up to ne springing level, are lined partly with earthenware facing-blocks nd partly with 1 to 1 cement rendering $1\frac{1}{2}$ inch thick. These ewers are made in six standard sizes, the largest, No. 1, being feet wide by 5 feet 2 inches high, and the smallest, No. 6, being feet 9 inches wide by 3 feet $6\frac{3}{4}$ inches high. Sewers smaller han No. 6 are formed of earthenware pipes 18 inches, 15 inches, nd 12 inches in diameter, laid with ordinary cement joints.

Except in a few special cases the flattest inclinations for the ewers are :—

For 12-inch pipes	1 in 150
„ 15 „	1 „ 200
„ 18 „	1 „ 250
„ Built sewers	1 „ 500

nd although only the usual appliances have been adopted for the leaning of the sewers, no difficulties have resulted from deposit, nd no flushing arrangements have been provided. A few f the sewers consist of 9-inch pipes laid to a minimum in- lination of 1 in 100, and in some special instances built sewers f larger size than No. 1 were employed. The largest oval sewer s 6 feet 5 inches by 5 feet, its inclination being 1 in 240. In some ases where sufficient depth for an oval sewer could not be obtained he section shown in Fig. 28, Plate 3, was substituted, the sewer eing of sufficient capacity to discharge the rain-water, while the rdinary sewage flow is carried in the small gutter formed in the entre of the invert. The ground in which the sewers are laid is the tierra pampiana," which is capable of standing with a vertical face vithout timber, and in many cases the larger sewers were con- tructed by digging a trench about 18 inches wide, which was then ndercut below to a sufficient diameter to enable the sewer to be onstructed.

Manholes and Ventilators.—The manholes, of the form shown in Fig. 29, Plate 3, are placed at each street corner, their average listance apart being consequently 1 square, or 142 yards. Owing o the absence of stone in Buenos Ayres, and the great expense f importing it, the road gratings were set upon a ring of hard

vitrified bricks set in strong cement mortar, and these have been found to resist in a satisfactory manner the heavy traffic which passes over them. These manholes act efficiently as air-inlets to the sewers, and with the outlets described it is found that ample ventilation is thus afforded, and that in many sewers a current of air can be distinctly perceived. As, however, the efficiency of the ventilation of any sewer is dependent on the number of houses drained by it, provision is made for the insertion of charcoal ventilators in the neck of the manholes, to provide against the emission of sewer-gas in the event of a reversal of the current through an insufficient number of house-drains being in action, or from any other local cause. So far it has not been found necessary to fix any of these charcoal boxes. In addition to the ventilation due to the manholes, a large volume of fresh air enters the sewers from the storm-water conduits with which they are in free communication.

Rain-Water Gullies.—The rain-water gullies, Fig. 30, Plate 3, are placed, four to each square, two on each side of the road, and consist of a brick chamber, 3 feet by 1 foot 6 inches by 4 feet 3 inches deep inside, built of 9-inch brickwork, the floor being formed with a brick invert on a concrete foundation. The gullies are placed beneath the footpaths, the water being admitted by a side grating, the upper surface of which forms a continuation of the curbstone. The position of the gullies on the edge of the footpath is rendered necessary by local circumstances, more especially the tramways, which traverse almost every street, the rails being generally laid at the side of the road, one within about 1 foot of the curb. In the side of each gulley is a cast-iron trap, and the communication with the sewer is effected by a 6-inch earthenware pipe.

Regulating-Chambers.—At the point in each district to which the sewers converge, a chamber is constructed for the purpose of regulating the flow of sewage and storm-water combined, so that when the latter amounts to more than a certain quantity the excess shall overflow into the storm-water conduit, the volume of sewage proper, and that due to $\frac{1}{4}$ inch of rain in twenty-four hours, being taken by the intercepting-sewer. These regulating-chambers, Figs. 31, 32 and 33, Plate 3, are constructed above the storm-water conduit and communicating with it. Across them the sewage is carried in cast-iron troughs communicating, by means of a vertical pipe, with the intercepting-sewer, which is constructed at a lower level. The capacity of this pipe is such that it will discharge into the intercepting sewer the maximum volume of sewage

in addition to the amount of rainfall referred to. On account of the different sizes of the several districts, this quantity varies considerably in the different chambers, and the flow into the intercepting-sewer is regulated in each case by a throttle-valve, Figs. 34, Plate 3, placed at the mouth of the pipe. This valve can be adjusted to pass the required quantity of water and sewage, and all in excess of this quantity, due to heavier rains, flows over into the storm-water conduit. The high price of fuel rendered it necessary to reduce to the utmost degree the quantity of sewage to be pumped, and the system described, by which the quantity of rain-water entering the intercepting-sewers could be controlled and reduced to a minimum, was accordingly devised.

Storm-Water Conduits.—The total quantity of storm water to be dealt with, calculated at 1½ inch of rain per hour, is about 9,000 cubic feet per second. This is conveyed to the river by nine conduits, Fig. 35, the greatest flow in any conduit being about 2,000 feet per second. The five principal conduits, which convey about 75 per cent. of the total, Fig. 36, are constructed for the most part of their length in tunnel, their internal dimensions being 14 feet wide by 12 feet high. They are lined with concrete 14 inches thick, faced with brick up to the springing of the arch. The remaining four conduits are of smaller size, and convey directly to the river the water from those districts situated upon its banks. All these conduits were constructed to discharge on to the foreshore in front of the town, and were so arranged as to be capable of extension, so as to flow into the open harbour proposed to be constructed according to Mr. Bateman's original project for the Port of Buenos Ayres. The substitution of a chain of closed docks has, however, rendered necessary the diversion of several of the conduits to a point beyond the limits of the harbour works. The designs for this purpose have been prepared by the Author's firm, and have been for some years in the hands of the Argentine Government; but the heavy cost rendered necessary by the prescribed conditions, and the slow rate at which the land reclamation connected with the port works has proceeded, have prevented until now the execution of this diversion.

Pumping Districts.—The district marked C, Fig. 1, which is situated on the slopes of the Barranca, and the narrow space between its foot and the river-bank, are at too low a level to be drained by gravitation, and the sewage from them is therefore raised at two small pumping-stations into the general system of intercepting-sewers. The general works are laid out to include

the subsequent addition of the district D, lying to the north of the town, from which it is intended to pump the sewage by engines to be erected at the lowest point of the district, near the Rio de la Plata. The arrangement of sewers, and their accessories in each of these pumping districts, will be similar to those already described for the districts sewered by gravitation. The districts lying to the south of the city, B, Fig. 1, Plate 1, are however drained by a system differing materially from that described. It is further intended to add a considerable portion of the land reclaimed by the port works as an extension of district B, when the reclamation shall be sufficiently advanced.

Intercepting-Sewers.—The branch intercepting-sewers are in most cases placed underneath the storm-water conduits, and frequently form part of the same structure, Fig. 36. They are mostly of the section shown in that Fig., viz., 4 feet 6 inches high by 3 feet wide, their dimensions being fixed by the consideration of accessibility rather than that of discharge. They are laid with adequate fall and a good velocity is maintained. These sewers are ventilated by shafts brought up to the surface of the road at each of the regulating-chambers, and also at certain intermediate points, where charcoal ventilators are fitted.

The branch sewers fall into a main arterial sewer which traverses the town from north to south, Fig. 37, its diameter varying between 4 feet 6 inches at the upper end and 6 feet 9 inches at the lower, the flattest inclination being 1 in 1,800. The mean velocity maintained in this sewer is $3\frac{1}{4}$ feet per second, and no provision has been made for flushing this sewer as no necessity for such has arisen. For that portion of its length which passes beneath district A, the sewer consists of a circular tunnel lined with three rings of brickwork. The portion which passes through district B, where the ground is exceedingly bad, is of the special construction shown in Fig. 38. The excavation for this portion was executed between sheet-piling, consisting of wrought-iron plates driven between timber guide-piles, and the sewer is formed of concrete built upon a flat invert resting upon a pitch-pine raft in the bottom of the excavation. In order to keep the sewer as far as possible in the surface layer of hard ground it is constructed with only 2 feet of cover beneath the paving of the street under which it is laid. Although the ground consists of soft mud and sand saturated with water, the work was successfully carried out, and no signs of settlement have, as far as the Author is aware, manifested themselves during the ten years since its completion.

Riachuelo Siphon.—At the southern boundary of the town the main sewer passes beneath the Riachuelo by means of an inverted siphon. It was at first proposed to construct this siphon within a cofferdam, but the experience gained during the destructive flood of the 22nd September, 1884, led to reconsideration of the design. During this flood 9 inches of rain fell in twenty-four hours, the Riachuelo rose 11 feet above its normal high-water level, and the current acquired sufficient force to destroy the two large iron bridges, one carrying the Ensenada Railway, and the other the road across the river in the immediate vicinity of the site selected for this work. The possibility of the recurrence of similar floods led to the adoption of a design which would offer no serious obstruction to the waterway during its construction.

The details of this siphon are shown in Figs. 39 to 44, Plate 3. The horizontal portion beneath the river consists of three elliptical tubes of cast-iron surrounded by concrete of a minimum thickness of 18 inches, the whole being sunk 2 feet below the river-bed. These tubes terminate at each end in abutments, in the upper parts of which chambers are constructed forming the termination of the main sewer at each end of the siphon. Communication between these chambers and the tunnels is effected in each abutment by means of six cast-iron pipes, 30 inches in diameter, in each of which is a valve for controlling the passage of the sewage through the three pipes under the river. Each abutment is surmounted by a small building; that at the northern, or upper end, contains apparatus for the removal of the sludge, which is arrested by a catch-pit constructed in front of the pipes, while at the southern, or lower end, the building contains a pulsometer and boiler for the purpose of laying dry the tunnels, and also a fan for their ventilation, during the operations of cleansing and repairs

The elliptical tubes are 5 feet high by 2 feet 3 inches wide, being thus of sufficient size to admit of a man passing easily through them from end to end. The bed of the river in which the siphon is constructed consists of soft slippery clay and fine sand, no solid foundation being available at a reasonable depth, and in the case of the construction of the bridge carrying the Great Southern Railway across this river, excavations for the piers were carried down to a depth of 90 feet without material of a more solid nature being met with. Any attempt therefore to secure a solid foundation was abandoned. The abutments are similar on the north and south sides of the river, and consist of two brick cylinders, 11 feet in external diameter, built upon a curb and

having vertical bolts and horizontal plates let into them at intervals. They were sunk close to the water's edge 32 feet apart from centre to centre. The total height of these cylinders was 58 feet, and they were sunk to a depth of 33 feet below the bottom of the river. No special means were adopted in sinking the cylinders, the excavation being performed by hand, and no great amount of water found its way into them during construction. When the cylinders had been sunk to a sufficient depth a plug of strong concrete was placed in the bottom. The concrete was composed of 1 of cement to 4 of sand in three of the cylinders, but in the fourth, where the quantity of water flowing in was greater than in the others, concrete as strong as 2 to 1 was found to be necessary. This strong concrete-filling was carried up to a height of 10 feet 6 inches above the bottom, the remainder of the cylinder being filled with concrete of 12 to 1. In one of the cylinders of the southern abutment this filling is omitted, the cylinder being utilized as a well to receive the drainage of the siphon when it should be necessary to empty any of the tubes. The drainage is removed from this well by a pulsometer pump.

The cylinders of the northern abutment were sunk satisfactorily to the correct positions, but those for the southern abutment shifted slightly towards the river, so that the two abutments were brought a few inches nearer together than originally intended. This movement did not cause any serious inconvenience, and the only measure taken to remedy the defect was the reconstruction of the upper part of one of the cylinders in order to bring the two into line.

Between the two cylinders of each abutment a circular space was enclosed by a cofferdam formed by a ring of sheet-piling ; the diameter of this ring was equal to the distance between the centres of the brick pillars, which thus formed a portion of the dam, and gave it the necessary stability to resist the tendency of the banks to cause it to slip towards the river. This cofferdam consisted of piles 14 inches square, planed to a true radius and driven accurately to a circular arc. These successfully resisted the pressure of 38 feet of slippery clay on the land side, and of a corresponding hydrostatic pressure on that next to the river. Within these cofferdams were constructed the central portions of the abutments, Fig. 41, the work terminating provisionally along the line marked *a b c*, Fig. 42. At this stage the piles at the front of the abutment were cut off below the water to make room for the horizontal portion of the siphon,

which was to be laid across the river between the abutments. This is divided into four spans and is supported at each end on foundations prepared for it in the base of the abutments. The intermediate supports consist of three cylinders 12 feet 4 inches in diameter, sunk to a depth of 25 feet below the under side of the siphon. These cylinders were sunk from stagings reaching above high-water level, and are constructed of brickwork built upon wrought-iron curbs and temporarily lengthened by means of iron casings so that the tops of the cylinders might be sunk to the required depth. When the necessary depth was reached the temporary casing was removed, and the top of the cylinder then remained at the proper level to receive the sections of the siphon. In sinking these cylinders they were loaded each with a weight of about 300 tons, which represented the skin-friction of the surface. When they had reached the depth required they were filled with concrete, and the bearing-surface was then 120 square feet and the weight per square foot $3\frac{1}{2}$ tons.

Each of the four spans of the siphon consists of a wrought-iron casing of elliptical section, Figs. 43 and 44, stiffened by means of bulb-iron rings and with temporary internal tie-rods in the direction of the major axis, so as to be capable of withstanding the pressure of the water due to the depth of the river. These casings were erected upon the foreshore, and the various cast-iron plates forming the tubes were put together inside them. In addition to these tubes, each casing contains two strong wrought-iron lattice-girders, extending from end to end, and giving it sufficient strength to support itself in water when filled with concrete and placed upon bearings at each end. The ironwork having been placed in position, the casings were lifted by a floating derrick and navigated out to their proper position. Water was then admitted and they were lowered into a channel dredged to receive them, so as to rest upon the cylindrical piers already sunk into the river-bed. This operation was satisfactorily performed, and no difficulty was experienced in placing the casings accurately upon these bearings. Access was obtained to the interior by temporary wrought-iron shafts attached to the casings, 5 feet in diameter, one at each end, reaching above high-water level. By means of these the space between the tube castings and the skin of the casings was filled with 5 to 1 concrete, thus enclosing the whole of the tubes and girders with concrete at least 18 inches in thickness.

Before depositing this concrete the girders in the interior of the casings were loaded to produce the final deflection in the girders. The weights were withdrawn as the concrete was deposited,

so that the girders were kept under an equal deflection throughout, and any tendency to rupture the partly-set concrete in the lower part of the casing, by the gradual increase of load during the filling, was avoided. No reliance was placed either upon the resistance of the mud in the river-bed or upon the transverse strength of the elliptical casings, as sufficient strength is provided in the concrete and the girders enclosed within it to allow each section, which is 52 feet in length, to remain supported upon the piers and abutments after the casings have completely rusted away. The junction between the adjoining lengths of the tunnels was effected by depositing concrete under water until the space separating the ends of the casings was completely surrounded. The bulkheads forming the ends of the casings were then removed from the inside, and the adjoining lengths of tube united by special castings made to template. A similar method was adopted for uniting the ends of the siphons to the castings which had already been built into the faces of the abutments.

Temporary Siphon.—Owing principally to the effects of the flood, considerable delays occurred in the adoption of the designs for the permanent siphon. The construction of the sewers of the city had in the meantime been pushed forward rapidly, and, with a view to enabling them to be connected to the house-drains, it was necessary to construct a temporary siphon of sufficient capacity to convey the sewage across the Riachuelo until the permanent siphon should be completed. This temporary siphon consists of four wrought-iron riveted pipes, 18 inches in diameter, carried over the river on a timber bridge specially constructed for this purpose. A circular well, 12 feet in diameter, was sunk on the northern bank of the river, and another well, 7 feet in diameter, on the southern bank, into which the two legs of the siphon were made to dip, a sufficient depth of sewage being maintained in these wells to prevent the entrance of air into the pipes. The siphon was started by filling the pipes with water from the town mains, the ends being temporarily closed by valves provided for the purpose. When once started, the working was maintained by expelling once a day the accumulated sewer-gas, for the reception of which a chamber was provided on the highest part of the pipe, and the removal of the gas effected by means of water introduced through an air-lock. This siphon was 368 feet in length, and designed to convey the sewage from 8,000 houses, together with the corresponding rain-water, with a difference of head between the two ends of 18 inches; this head could however be increased by allowing the sewage to accumulate in the well at the upper end, and the discharge was

thus augmented, so that by the time the permanent siphon was brought into operation the number of houses drained amounted to nearly 14,000. The siphon worked well, and in no instance was its discharge interrupted during the four years that it was in operation.

Outfall Conduit.—The continuation of the main sewer beyond the siphon under the Riachuelo, conveys the sewage of the entire city to the outfall in the Rio de la Plata, and is 14½ miles in length. For description it may be divided into two separate sections, the low level, which connects the siphon with the pumping-station at Puente Chico, where the sewage is raised a height of 43 feet, and the high level, which conveys it after being pumped to the outfall in the Rio de la Plata.

The first portion of the low-level conduit passes through soft ground of a nature similar to that met with in district B, and a corresponding section and mode of construction were adopted. For the remainder of the distance, ground of a harder description was available, and the conduit was built of circular section, 7 feet 6 inches in diameter, and constructed of concrete 15 inches thick. This section was adopted for the remainder of the low-level, and for the whole of the high-level conduit when it was not under pressure. The fall both of the low- and high-level conduits was at the rate of 1 in 2,640 for the portion 7 feet 6 inches in diameter, and at the rate of 1 in 1,800 for the portion 6 feet 9 inches in diameter. The invert of both sections is lined with brick, and the sides rendered in cement 1½ inch in thickness up to the springing of the arch. Access is obtained to the conduit by means of manholes, constructed, wherever the conduit passes through low ground, at such a height as to be raised above the reach of floods. At each manhole a ventilating tower, 10 feet high, is provided to serve as the base of a chimney, to be constructed whenever the district around them becomes populated. Many of these chimneys have been erected and others continue to be added as required.

Puente Chico Pumping-station.—This establishment consists of a straining-house where the sewage is passed through gratings having bars 1 inch apart, and of an engine-house containing two pairs of compound beam-engines and pumps,[1] capable of delivering 36,000,000 gallons of sewage per twenty-four hours against a head of 43 feet. To complete the drainage scheme, it was necessary to duplicate this pumping-station. Engines for this purpose were constructed and delivered to the Argentine Government in 1892,

[1] Minutes of Proceedings Inst. C.E., vol. lxxviii. p. 17.

but have not yet been erected. They are similar to those referred to, with the exception that they work with a steam-pressure of 120 lbs. per square inch. Economisers have also been provided, through which the feed-water is to be passed. This establishment also comprises an artesian well for the supply of the necessary feed-water, as well as ample coal-stores, and the necessary accommodation for the staff. The pumping mains between the engine-house and the commencement of the high-level conduit are three in number, 42 inches in diameter, of cast-iron, and 3,950 feet in length.

Near the termination of the high-level conduit, a stream of considerable size, called the Arroyo Jimenez, is crossed. The conduit over the ravine in which this stream flows consists of three cast-iron pipes 42 inches in diameter, supported upon brick piers erected in the bed of the stream. The pipes are held down to the piers by straps and anchor-bolts. The piers are placed close to each of the pipe-joints and are of a substantial character, being built upon solid foundations to resist the torrents which periodically sweep down the bed of this stream. The pipes are uncovered, and being exposed to the sun are subject to a great range of temperature. Any difficulties arising from this cause are guarded against by the adoption of expansion-joints in the form of glands at each end, and gun-metal rollers at each point of support, so that the pipes may expand freely when any change of temperature occurs. The pipes are of the ordinary wide socket type jointed with lead, and prevented from drawing out of each other by set-screws inserted in the sockets and screwed up tightly to grip the spigots. The pipes have now been in position for nine years, and have proved in every way satisfactory.

Outfall.—The outfall conduit terminates on the face of the Barranca at a point opposite to the site chosen for the outfall into the river, but separated from it by an extensive marsh. Across this marsh the sewage is carried in cast-iron pipes 42 inches in diameter. Two lines of these pipes have been laid, and it is intended to lay a third line as soon as the increased quantity of sewage shall render it necessary. The final discharge of the sewage takes place at a distance of 1,500 feet from the bank of the river, and the pipes for that distance were laid in a cofferdam which it was found convenient to use temporarily as a jetty for landing materials. The pipes are laid with turned and bored joints, with a lead joint every 50 yards. When exceptional quantities of water were met with, rust joints were substituted for the lead joints.

Boca and Barracas Drainage.

Physical Conditions of the District.—The large area B, which lies between the Barranca and the Riachuelo at the southern extremity of the city, differs in physical conditions from the other districts of the city so that it was impossible to include it in the general scheme. This portion of the city is but little above the level of ordinary high water of the river, parts of it being only at 45 feet above datum. The ground rises somewhat towards the north-east, but the highest level is only 53 feet above datum, or only 1 foot above the highest flood-level. The municipality, when laying out new streets, raises the surface to a minimum level of 47 feet, and this may be taken as the general level of the surface of the ground to be drained. The banks of the Riachuelo have been artificially raised to a level of 48 feet above datum, so as to lift the houses built upon them out of the water, and the wharves of the south tidal-basin are at the level of 53 feet. The western boundary of this district is formed by the embankment of the Southern Railway, so that it is enclosed on all sides, and the natural drainage of the land is thus cut off in every direction.

In such low land the sewers require to be laid in many instances below the level of the river, and as a result could not be used for conveying storm-water to it, as is done in the other portions of the city, while the pumping of the rain-water is rendered impracticable by the extreme violence and suddenness of the storms. Moreover, at exceptionally high tides which occur at frequent intervals, the greater part of the district is under water, and during the storm of 1884 already referred to, the whole area was flooded to a depth of 5 feet. Under these circumstances it was necessary to exclude the floods from the sewers, and no attempt was made to deal with the rain-water by means of the sewerage works, but a separate system of surface drains was constructed to convey it to the river. This, however, was constructed by the Municipality.

Owing to the nature of the ground in the district, consisting of a comparatively hard crust, varying between 2 feet and 4 feet in thickness, overlying a bed of soft alluvial deposit, the construction of sewers was exceedingly difficult. Hard ground is met with in a few places at a depth of about 20 feet below the surface, but its presence cannot be relied upon, and in the vicinity of the Riachuelo a solid foundation is not procurable at a much greater depth. The area of the district is equal to nearly 400 manzanas (1,600 acres), of which about one-half is at

present inhabited, and the population numbers some 60,000. Provision was made, however, in all the principal portions of the works for a future population of 500 per manzana, or 200,000 in all, and also for the ultimate extension of the district over a considerable area of the land to be reclaimed when the Port Works, now under construction, are completed. Although the provision for future population may appear a large one, yet it is not excessive when the rapid increase in this district is taken into consideration. It is also probable that in some of the sub-districts the maximum density of population found in other parts of the city will be reached within a comparatively short time.

General System of Sewerage adopted.—For the purpose of sewering the whole area of district B it is divided into eighteen sub-districts, Fig. 37, Plate 3. Of these that one only in immediate proximity to the main intercepting-sewer is capable of being drained by gravitation, and the other seventeen are dealt with by means of a special system now to be described. The local requirements which rendered it necessary to divide this district into so many sub-districts were, in the first place, that the sewers must be kept as far as possible within the stratum of hard ground lying on the surface, in which excavation was comparatively easy; and in the second place, that, in order to obtain an adequate fall in the sewers, their length should not be too great, or they would dip below the stratum of hard ground. It was essential therefore, as the districts were so numerous, that some system of distribution of power should be adopted to remove the sewage from them, and, as the volume was considerable, it became apparent that transmission of power by hydraulic pressure for actuating sewage-pumps in each district would be the most economical and also the most reliable. So far as the Author is aware, the works to be described are the largest hitherto constructed on this system.

Sewers.—The sewers in each of the pumping-districts converge to a central point where they discharge into a pump-well. The principal conditions regulating their design are, that the bottom of the trench shall not be at a lower level than 38 feet above datum, giving a maximum depth of excavation in most sub-districts of 9 feet; that the cover over the upper end of any sewer shall not be less than 3 feet 6 inches; and that the inclination should not be flatter than 1 in 300. The limits of the districts were arranged so that their areas should be as large as possible consistent with the fulfilment of these conditions. The utmost advantage was taken of the slight natural inclinations which existed in the

surface of the ground, so that the number of sub-districts should be reduced as far as possible.

The sewers are 9 inches and 6 inches diameter, and consist of earthenware pipes in all cases where these could easily be laid, but in many of the deep trenches iron pipes, with rust joints, were substituted. In a few cases several of these pipes were united in one length before being lowered into the trench, the joints being made above ground; in all cases where iron pipes were employed, a lead joint was introduced at every 50 yards. Where earthenware pipes were used in situations in which large quantities of water or running sand rendered it necessary to execute the work with the utmost despatch, a special form of joint was employed. This consisted of a narrow ring of cement cast on to the spigot of the pipe, fitting accurately into a similar ring cast inside the socket, the remainder of the joint being filled up with Portland-cement mortar. By this means the pipes could be rapidly laid and accurate centering insured, whilst the extra cost did not exceed $1\frac{1}{2}d.$ per joint. The pipes were, with few exceptions, laid upon timber foundations, either in the form of rafts, or of short piles driven in the bottom of the trench, one to each pipe-joint. The latter method was found to give the best results, as the rafts frequently sank into the soft ground when the weight of the pipe came upon them, being undermined by the constant pumping that was necessary. No portion of any trench was allowed to be refilled until the whole length of the sewer in it had been laid, and until the soundness of the work had been tested by being exposed to water-pressure under a head of $6\frac{1}{2}$ feet; and until all unsound joints, which were discovered by this test, had been surrounded by concrete. The whole of the trenches were timbered with sheet piling, composed of 3-inch planks, driven by means of heavy mallets.

Manholes, &c.—Where the depth of the sewer permits, the manholes are of the same form as those already described for the gravitation districts. In many cases, however, the sewer is so close to the surface, that only sufficient depth can be obtained for the concrete neck, which is, in these cases, modified in form as shown in Fig. 45, Plate 3, and a separate provision is made for obtaining access to the sewer by movable covers placed underneath the road. As systematic flushing of these sewers is provided for, it is not anticipated that the covers will need frequent removal.

The arrangements for ventilating the sewers are the same as in the other districts of the city. A special provision is, however, necessary to prevent the flood-water entering through the manhole

gratings, and for this purpose an apparatus, shown in Fig. 46, is introduced, by which, on any large quantity of water entering a manhole, a valve is closed automatically, and the water is prevented from passing into the sewer. A small leak-hole in the side of the apparatus allows this to empty itself after the subsidence of the flood, and thus opens the valve again and restores a free entry for the air.

Flushing Arrangements.—At the upper extremity of each sewer, where the natural flow is small, provision is made for the automatic flushing of those sewers in which the fall is less than 1 in 100. This is effected by the admission of water under pressure from the town mains. The apparatus, specially designed for this purpose, is shown in Figs. 47 and 48, Plate 3. It consists of a small tank provided with an automatic siphon, the frequency of discharge of which is regulated by a drip from the supply-pipe, and in which the fall of water actuates a ball-valve, placing the distributing pipe of the water-supply in communication with the sewer. By these means a copious supply of water is periodically sent into the sewer, the flush lasting until the partial refilling of the tank closes the valve by raising the ball. Both the duration of the flushes and the interval separating them is capable of adjustment. The flushing apparatus is placed under the footpath in close proximity to the water-main, and is connected with the sewer by a 4-inch cast-iron pipe provided with a deep siphon-trap, discharging into the manhole. The number of manholes provided with flushing apparatus is about one-sixth of the total.

House-Connections.—The external portions of the house-drains are laid to a minimum inclination of 1 in 40, and consist of pipes 4 inches in diameter of earthenware or iron, according to the nature of the ground. The internal portions are in course of construction in this district, according to by-laws similar to those regulating the construction in the other districts, with some slight modifications to adapt them to the local circumstances, the chief of which consists in placing all the inlets to the sewers at a level of at least 52 feet above datum, or 5 feet above the ground-level over the greater part of the area, in order to exclude flood-water from the sewers. The houses in the localities where this provision will be necessary are of the poorer classes, constructed either of timber or corrugated iron, and are in most cases at present raised on piles to nearly the above-mentioned level. In addition to the external house-drains laid for the houses already constructed, branches are provided in the sewer at intervals of about 25 feet for future con-

nection, which, until made use of, are closed with earthenware covers, cemented into the sockets of each branch.

Pump-Wells.—The wells in each district into which the sewers discharge are 13 feet 4 inches in diameter, and between 18 feet and 23 feet in depth, Figs. 49 and 50, Plate 3. They were sunk from the surface of the ground upon wrought-iron curbs, and are formed of brickwork, 18 inches thick, set in cement mortar, the outer circumference being plastered with the same material. Considerable care was necessary in the sinking of these wells in consequence of their movements being extremely irregular. In some cases it was necessary to force them downwards by heavy weighting through layers of tenacious clay, and at other times they descended with inconvenient rapidity by their own weight. Large quantities of water were encountered, and the laying of the concrete floors was attended with considerable difficulty. In some cases hard tosca was unexpectedly met with before the well had been sunk to the full depth, and, in several of the wells, vertical cracks occurred in consequence of the uncertain character of the ground through which they were sunk. In spite of these difficulties, however, all the wells were satisfactorily completed and made watertight.

Before entering these wells the sewage passes through small chambers, placed immediately outside them, in which are fixed two planks, the sewage being made to pass over one and under the other, so that both heavy and floating solids are arrested, and the necessity of cleaning out the well itself—a difficult matter owing to the quantity of machinery it contains—is to a great extent avoided. An additional use to which these manholes are put is that, by instituting a night inspection, any leakage that may occur into the sewers can be immediately localised and measures taken to repair the defect.

Pumping Machinery.—In each well are fixed two pumps for raising the sewage, the cylinders and the suction- and delivery-pipes of which are in the well itself, while the actuating machinery is enclosed in an ornamental kiosk erected over it. The pumps are single-acting, and the glands through which the plungers work are situated on a level with the floor of the kiosk; the valves consist of a single flap, to avoid, as far as possible, solid substances in the sewage being caught by them. The plungers of the pumps are forced downwards by means of a hydraulic ram, and are withdrawn by two push-back rams constantly open to the hydraulic pressure, Fig. 51. The valves for admitting the water to the working cylinder, through the centre of the ram, are actuated by means of tappets moved by the plunger. The water, after it

has done its work, is allowed to escape from the hydraulic cylinders into a lantern gland in the pump cylinder, which prevents the grit suspended in the sewage from coming into contact with the packing of the pump gland. The pumps are started and stopped automatically by floats rising and falling with the surface of the sewage in the well, and are so arranged that the hydraulic pressure is admitted to the rams whenever the sewage has reached the maximum level, and cut off when it has fallen to a minimum level. The floats in each well are so arranged that either pump can be worked for the ordinary service, but the second is always at hand, except when under repair, to be brought into use automatically in the event of any failure of that in service or of a sudden influx of water. The floor of the kiosk is carefully sealed to prevent sewer gas from passing through it, the rods for actuating the starting and stopping valves passing through glands for the same object. The well is efficiently ventilated by means of a 9-inch wrought-iron pipe led up inside and through the roof of the kiosk, and so arranged that a chamber containing charcoal can be fitted if required. The hydraulic pressure adopted is 750 lbs. per square inch, and the plungers of all the pumps are 30 inches in diameter. Owing, however, to the different areas of the districts, it was found necessary to adopt two sizes of pumps, and five sets are therefore fitted with plungers having a 4-foot stroke, the remaining twelve sets having a stroke of 3 feet, the discharge being calculated respectively at 3·05 cubic feet and 1·75 cubic foot per second, the maximum amounts of sewage flowing from the largest district in each of the groups.

The kiosks are octagonal in shape and are constructed of cast-iron; they are of ornamental appearance and are situated in the centre of the road at a point where two streets cross each other, to avoid obstructing the thoroughfare. The panels on each side are arranged with hinges so that access may be obtained to the machinery without difficulty, and the building is protected against damage from vehicles by substantial railings encircling it.

The sewage discharge is calculated upon an average consumption of water of 40 gallons per head per day throughout the year for a population of 500 per manzana, and each pump has a capacity of at least two and a half times this amount. This allowance is somewhat large when compared with the ratio usually assumed in English sewerage works, but it is not greater than is warranted by the local circumstances. The high temperature which prevails during the summer months leads to a consumption of water during certain hours of the day of at least double the average of the year.

In addition it is necessary to make provision for the water used in flushing the sewers and for possible leakage into them. But little effect can be produced in equalizing the flow by storage in the sewers and wells, on account of the small size and short length of the former and of the small capacity of the latter, equal only to about ten minutes' discharge from one of the larger districts.

Pumping-Mains.—These consist of cast-iron pipes varying in diameter between 24 inches and 8 inches, and of sizes to give velocities of flow between 2 feet and 3 feet per second. The pipes are so arranged that an alternative route is available from every pump-well. Each pipe is provided with an air-vessel placed beneath the road alongside the pump-well, which equalizes the pressure forcing the sewage along the mains, and attached to these are the usual gauge-glasses and cocks. The pipes are provided with valves at all the junctions, for isolating the various lengths of piping, and with drain-valves for emptying them. These valves are of special design, having single faces, the tongue being formed with a cutting edge by which the face is scraped clean by the act of closing. There are no air-valves on these pipes, the small pressure under which they would work rendering the action of such valves uncertain; but the pipes are so arranged that all the summits correspond in position with the pump-wells. At each summit a small air-cock is inserted, which is left slightly open during pumping, so that the air or gas is forced out of the pipe into the well, from which it is carried off by the ventilator. The pipes are provided with cover-plates, bolted on to them and placed at distances of 2 squares apart, for the purpose of giving access to the interior. To facilitate inspection, a vertical pipe, 8 inches in diameter, is brought up to the surface of the ground at each of these points for use as a lamp-hole.

Central Power-Station.—The hydraulic power is distributed from a pumping-station situated at the northern extremity of the district, this position being chosen with a view to future extension in this direction of the area drained. The plant consists of two horizontal pumping-engines, each capable of delivering into the accumulators 175 gallons of water per minute against a pressure of 800 lbs. per square inch. The power of each engine is sufficient to actuate all the pumps at the same time, while the other engine is kept in reserve. The engine-house is of sufficient size to accommodate a third engine of similar power when required. The accumulators are two in number, 18 inches in diameter by 20 feet stroke; the weight-boxes are of larger size than usual, as ordinary

sand and broken stone were the only weighting materials available. The pressure-water is taken from the town mains and is stored in a tank over the boiler-house. Before entering this tank, however, it is passed through the surface-condensers of the engines and utilized for condensing purposes.

Hydraulic-Pressure Pipes.—The high-pressure water is conveyed by cast-iron pipes which vary in diameter between 5 inches and 3 inches, with 2-inch branches for the supply of the pumps. The diameters of these pipes were fixed on the basis that they should, as far as possible, have a hydraulic gradient of 1 in 100. The pipes are laid in circuits, so that alternative supplies are available to every pump, and numerous valves are provided for closing off any length which it may be necessary to put out of service. The pipes are laid in shallow trenches to keep them within the superficial layer of solid ground; the depth of cover being in general 2 feet 9 inches. The whole of the hydraulic installation was executed by the Chester Hydraulic Engineering Company, and the pipe-joints, valves, and other fittings are of the standard patterns employed by that firm.

Materials.

The country around Buenos Ayres is devoid of good building stone, which is not found in the Argentine Republic nearer than Azul, 250 miles to the south, where limestone and granite of good quality are worked. The dwelling-houses and public buildings in the city at the date of the design of the Sanitary Works were constructed of a porous native-made brick laid in mud or slime, composed of the surface soil tempered with water. Since that time, owing to the opening of the railways, lime is burnt at Azul and also at Cordoba, 500 miles to the north-west, and brought into Buenos Ayres for the manufacture of mortar for building purposes. The architectural adornments of the houses, mostly in the Italian style and frequently very elaborate, are of plaster, composed of these limes, to which are added Portland or Roman cements imported from Europe.

When the works were commenced, an attempt was made by the Government to produce a reliable cement from materials found in the locality. All the necessary machinery was procured for starting the manufacture and an experienced superintendent appointed, but, although some fair samples were produced, the quality was not reliable, and, as the cost far exceeded that of the imported article, the manufacture was abandoned, and the

whole of the Portland cement used in the works was imported from England. For the decoration of buildings in Buenos Ayres the marble of Azul is now used, but by far the larger quantity which has been employed has been imported from Italy. Granite of good quality is found in the Republic of Uruguay, on the opposite side of the Rio de la Plata, but it is less expensive, when large quantities are required, to import finely dressed granite from England. The sand used in the works is procured exclusively from the Republic of Uruguay, as none exists in the vicinity of Buenos Ayres. Under these circumstances it was necessary to consider what was the most reliable and the cheapest building material to use in the construction of the works. The clay used in the manufacture of the native bricks was of good quality, and, as it appeared probable that the defects in them might be in a great measure removed by proper pressing and burning, experiments were made, and a factory subsequently established to produce them in large quantities. The bricks made in this way were found to be reliable, and it was further ascertained that if the burning were carried to excess vitrified bricks were produced, which, although frequently defective in shape, were serviceable for resisting heavy traffic in the streets of the city. Concrete, composed of Portland cement, broken brick and sand, in various proportions, was also largely used in the construction of the works.

It is worthy of note that, owing to local circumstances, the cost of concrete and brickwork are so nearly equal that for a thick wall of concrete it was found advisable to dispense with casings by facing the wall with brick, and filling in the hearting with concrete. Terra cotta imported from England was largely used for the decoration of the various buildings connected with the works, whilst in other cases the ornamental portions of the buildings were made in plaster, which in that climate is found to be reasonably durable and less expensive than terra cotta. No stone was used in the construction of the works with the exception of the bedstones upon which the machinery is laid. Where timber was employed and durability was essential the native wood known as Quebracho Colorado, which grows in the northern part of the republic, was used. For roof timbers and other similar purposes where lightness and ease of erection where essential, Canadian pine was used in preference to the native hard woods. For window-frames Urunday, and for doors Paraguayan, cedar, varnished, were generally adopted.

Conclusion.

An account of the financial arrangements and of the order in which the works were constructed, together with particulars of the cost of the undertaking, is given in Appendixes I and II.

In Appendix III is shown approximately the consumption of water per head during the last twenty years. No accurate figures are available as to the population supplied; the Table is, however, calculated from data which are known to be fairly correct. The consumption per head gradually diminished whilst the old works were still in use, showing clearly the insufficiency of the supply. A sudden increase from 18·5 gallons to 29 gallons per head occurred as soon as the new engines were brought into service, and the consumption remained fairly steady at an average of 30 gallons until 1889. During this period no restriction was placed upon the supply, so that this amount per head may be taken as the quantity of water naturally consumed by the town when in its unsewered condition. A considerable increase took place as soon as the sewers were brought into action, becoming more marked as the number of houses connected with them increased.

As the connection of the houses with the sewers is still incomplete the amount of water naturally taken per head of the population using the sewers cannot be ascertained; but an estimate may be made by allowing the average amount of 30 gallons per head for each inhabitant of the unsewered parts of the town, and dividing the remainder of the water supplied among the inhabitants of the sewered parts. The consumption per head of the latter is then found to be :—

1891	. . . . .	71	gallons per head.
1892	. . . . .	66	„ „ „
1893	. . . . .	64	„ „ „
1894	. . . . .	58	„ „ „

These figures show a steady decline as the inhabitants of the town grow more familiar with the use of the sewers, and as the custom which prevails of leaving taps running, with the false idea of flushing them, becomes less common. It is probable, however, that a considerable amount of waste still takes place, and that by the time the houses are all connected to the sewers, and the ordinary precautions adopted, the consumption will be still further reduced.

The increase in the scope of the works decided on in 1888 (Appendix I) has been more than justified by the progress of the

city since that date. The population is now stated to be over 600,000, or, when certain suburbs which lie outside the drainage-area are excluded, about 560,000. Of these about 360,000 had before the end of 1894 been connected to the water-supply and about 220,000 to the sewers.

A comparison is made in Appendix IV between the mortality for the year 1887, before any houses were connected to the sewers, and the year 1893, the last for which complete returns are available. The death-rate from all causes has been reduced from 32 per 1,000 to 24·3, or by 25 per cent., and that from typhoid fever alone from 0·675 to 0·360, or by 37 per cent., although at that time only 35 per cent. of the houses were in connection with the sewers. The death-rate from the three principal infectious diseases for the seven years ending 1894 is shown in Appendix V. The improvement in the sanitary condition of the city, as the sewers have been brought into further use, is clearly marked, and fully justifies the hope that, when at length the benefits of the sanitary works shall have been extended to the whole of it, the city of Buenos Ayres will take its place as one of the healthiest in the world.

The resident engineer in charge of the works from their commencement in 1871 till 1875 was Mr. Alfred Moore, M. Inst. C.E.; from 1875 till 1877 the late Mr. George Higgin, M. Inst. C.E.; from 1882 till 1888 Mr. Carl Nystromer, M. Inst. C.E.; and from 1888 till 1891 Mr. L. J. Lowe, M. Inst. C.E. During these periods the late Mr. J. F. La Trobe Bateman, F.R.S., Past-President Inst. C.E., and the Author, paid frequent visits to Buenos Ayres, directing the arrangements connected with their design, and execution of the works.

The Author desires in conclusion to mention the valuable services rendered during a series of years by his Assistant, Mr. Arthur Honeysett, Assoc. M. Inst. C.E., who, for a considerable period, was in charge of the drawing office in Buenos Ayres, and who has assisted in the preparation of this Paper. Also of Mr. W. Fox, M. Inst. C.E., and Mr. C. E. D. Waring, M. Inst. C.E., who assisted in the preparation of the designs for the works; and, lastly, of Mr. Olaf Boye, of Christiania, who, under the direction of Mr. Carl Nystromer, M. Inst. C.E., prepared the architectural designs of the service-reservoir and the other buildings connected with the works.

The Paper is accompanied by drawings, from which Plates 1, 2 and 3 have been prepared. [APPENDIXES.

APPENDIXES.

APPENDIX I.

Historical Account of the Execution of the Works.

The works were projected in 1871, and their construction commenced two years later, continuing vigorously until the year 1877, when financial and political difficulties caused the suspension of operations for several years. The portions of the waterworks constructed during this period consisted of the land section of the intake tunnel, the intake pumping-station and two of the three settling-ponds. The main pumping-station had also been completed, but no pipes were laid from it, so that the engines remained unused. During this period the administration of the works was in the hands of the Provincial Government of Buenos Ayres, of which province the City was at that time the chief town.

By the year 1882 the difficulties referred to had been to a great extent overcome, the City having, as the result of a civil war, passed from the hands of the Provincial Government and become the capital of the Republic. It was then decided to resume the construction of the works under the administration of a Commission of the National Government, and a start was again made in 1883. The large pumping-engines were brought into action in the following year, ten years after their erection, and the works for the better filtration of the water were commenced, as well as the laying of the new system of piping throughout the City. During the former period of activity most of the large storm-water conduits had been finished, and the construction of the sewerage works, which had made but little progress, was now pushed rapidly forward. During the years 1884 and 1885 the whole of the works, so far as they had at that time been undertaken, were almost completed, but during the year 1886 an almost entire suspension of operations took place, so that no use could yet be made of the large amount of work accomplished during the preceding years. At this period the water-supply works had been virtually completed, with the exception of the service-reservoir; while of the sewerage works the only important part remaining to be constructed was the siphon under the Riachuelo, although, in both divisions of the works, numerous portions of a subsidiary character still remained to be executed.

The works had up to that time been constructed upon the basis of a population of 200,000, the same figure which had been adopted sixteen years previously. The census of 1887 showed, however, a population of 425,000, and it was evident that this was increasing at a rapid rate. At this juncture the Government decided to entrust the completion of the works to private hands, and, after prolonged discussions in the Argentine Congress and lengthy financial negotiations, arrangements were made, in July, 1888, by which the completion of the works was handed over to a company, formed in London, which undertook the execution and maintenance of the works on the following terms:—

The company purchased the works as they then stood for the sum of £4,200,000, and undertook the completion of all unfinished works and the construction of the extensions necessary for a total population of 500,000 (corresponding to a consumption of water of 20,000,000 gallons per day). In return

the company was to receive the revenue from the works for a period of thirty-nine years, reckoned at an average rate of £14 8s. per annum per house, the average number of inhabitants per house being thirteen.

Rapid progress was made during 1889 and 1890, and the sewering of the houses commenced in the latter year, but again financial and political difficulties led to a suspension of progress. The crisis which had become manifest during the latter year was brought to a culminating point by an armed insurrection, and by a resulting depreciation in the value of the inconvertible paper dollar, which rendered it impossible for the Company to collect rates of a value corresponding to the gold payment upon which their undertaking had been based. At the time of the granting of the concession the average rate corresponded to an annual payment of 120 paper dollars per house, but under the altered circumstances this payment did not yield more than £6 per annum in place of £14 8s. The impossibility of sufficiently increasing the revenue, and the refusal of many of the inhabitants to subject themselves to the payment of any rate whatever, added to the difficulties caused by the failure of Messrs. Baring, forced the Company to surrender the works back into the hands of the Argentine Government. The transfer was arranged on the basis of the Company receiving $25,500,000 in Water Works Bonds at 80 per cent., as well as other concessions, the total value received at the then market price of the above securities being about £5,000,000. Upon re-entering into possession of the works, the Government immediately reduced the rate to 5 per cent. upon the rental; this reduction entailed a heavy loss of revenue, and at present the surplus income is by no means sufficient to pay interest on the capital expended.

It will be understood, that under the above circumstances, the task of estimating the actual cost of the works is one of great difficulty. The above-mentioned capital sums include expenditures of various classes which do not fall within the cognizance of the engineer, and the case is further complicated by the fact that while the works were in the hands of the Company the engineers had no control over or knowledge of the expenditure, and that, on their retirement from the direction of the works, the different portions were in different stages of advancement, the extension from the smaller to the larger basis having been only incompletely carried out. Moreover, many of the payments, in the cases where they are known, are in a currency the exchange value of which varied from day to day. The Author has, however, endeavoured to form as accurate an estimate as possible of the total cost of the works after the elimination of all items of extraneous expenditure, and also of that necessary to place the portions not yet entirely completed upon the basis of 20,000,000 gallons of water per day. The result of these calculations is given in Appendix II. In all cases payments in local currency have been reduced to sterling at the rate of the day on which they became due.

The total cost of the waterworks is found to be £2,044,478 for the works proper, and £2,506,932 if the value of the old works and that of land and administrative charges be included. For the sewerage works these figures are £2,693,112 and £2,997,112 respectively, the total cost of the whole works being £5,504,044.

The sums expended during the first two periods amounted to £3,789,020, considerably less than the sum of £4,200,000 for which the works were sold. It should be stated that the former sum does not include a number of items, such as the brickworks and stores, which, although not forming part of the works themselves, were included in the property transferred to the company. In addition to these items, the official capital account includes certain other

sums, such as compensation for the stoppage of the works, and cost of the maintenance of certain portions of them for the period during which they were unproductive, as well as that of considerable quantities of pipes and other materials purchased for the works, but used for other public purposes. These have also been excluded from the total cost of the works above stated. The expenditure upon the works connected with the water-supply, when distributed over a population of 500,000, was thus at the rate of £5 per head, and upon those connected with the drainage at £6 per head.

In comparing the cost per head for the water-supply with that for similar works in the United States and in England, it is found that in the former case, for twenty-one of the largest cities with pumping supplies, the cost per head of the population corresponds to an average of £5 12*s.* for an average consumption per head of 73 gallons. In England, for twenty of the largest towns, the average cost per head, for an average consumption of 30 gallons per head, is £3 8*s.* The cost of the works connected with the water-supply of Buenos Ayres, therefore, does not differ largely from those of the principal towns in the United States. When comparing their cost with similar works in England, the circumstances under which they were executed must be carefully considered.

At the date when the works were projected nothing approaching them in magnitude had been attempted in the Argentine Republic, and, farther, the larger portion of the materials used in their construction were transported from England, a distance of nearly 7,000 miles, at a time when freights were high.

The following are a few of the schedule prices attached to one of the principal contracts under which a considerable portion of the work was constructed, the dollar being at about its par value of 4*s.*:—

	£	*s.*	*d.*	
Bricks	4	3	4	per 1,000.
Portland cement	6	11	4	per ton.
Broken brick for concrete	1	0	0	„ „
Sand	1	0	0	„ „
Brickwork in cement	5	0	0	per cubic yard.
Concrete, 6 to 1	4	0	0	„ „ „
Granite ashlar	0	13	4	„ „ foot.
Timber (pine)	0	6	0	„ „ „
Ordinary labour	0	4	0	per day.
Skilled labour	0	8	0	„ „
	to 0	12	0	„ „

After the declaration of forced currency in the year 1885 considerable confusion took place with regard to the prices of all commodities. Imported articles naturally maintained their gold value, whilst native productions were of less value when estimated on a gold basis, according as the premium in gold rose. The lowest price of bricks per 1,000 during this period was £3 10*s.*, of Portland cement £4 3*s.*, whilst that of ordinary labour fluctuated between 4*s.* and 1*s.* 6*d.* per day.

The rise in the gold premium naturally affected the relative prices of concrete and brickwork, and it was found that, when the dollar stood at about half its par value, they became equal in price.

APPENDIX II.

TOTAL EXPENDITURE AND ESTIMATED AMOUNT NEEDED TO COMPLETE THE WORKS ON THE BASIS OF 20,000,000 GALLONS OF WATER PER DAY.

	First Period, 1874–81, Provincial Government.	Second Period, 1882–88, National Government.	Third Period, 1888–91, In hands of Company.	Fourth Period, since 1891, National Government.	Total.
A. *Water-Supply.*	£	£	£	£	£
1. Cost of construction—					
Certificates and accounts . .	769,600	389,267	401,499	65,000	1,625,366
Estimates	..	..	211,340	..	211,340
Expenditure on construction of waterworks to end of 1893	..	..	..	..	1,836,706
Cost of completing waterworks—					
Materials purchased . . .	..	..	..	8,405	8,405
Estimates	..	..	..	199,367	199,367
Total cost . . .	769,600	389,267	612,839	272,772	2,044,478
2. Other charges due—					
Construction of old works .	132,000	524	..	..	132,524
Proportion of land, engineering and general charges .	84,000	52,430	..	..	136,430
Estimates—					
Engineering and contingencies	..	..	140,000	53,500	193,500
Total cost of waterworks . . .	985,600	442,221	752,839	326,272	2,506,932
B. *Sewerage and Drainage.*					
1. Cost of construction—					
Certificates and accounts . .	1,068,470	1,108,669	128,584	..	2,305,723
Estimates	..	..	312,553	..	312,553
Expenditure on sewerage and drainage to end of 1893 .	..	..	..	..	2,618,276
Cost of completing works—					
Materials purchased . . .	..	..	..	34,620	34,620
Estimates	..	..	..	40,216	40,216
Total cost . . .	1,068,470	1,108,669	441,137	74,836	2,693,112
2. Other charges due—					
Proportion of land, engineering and general charges .	113,260	70,800	..	..	184,060
Estimates—					
Engineering and contingencies	..	..	103,440	16,500	119,940
Total cost of sewerage and drainage works	1,181,730	1,179,469	544,577	91,366	2,997,112
Total cost of works	2,167,330	1,621,690	1,297,416	417,638	5,504,044

APPENDIX III.

CONSUMPTION OF WATER FOR TWENTY-ONE YEARS FROM 1874 TO 1894.

Year.	Average Consumption per 24 hours.	Approximate Population Supplied.	Percentage of Population taking Water also using Sewers.	Average Consumption per Head per Day.	Remarks.
	Gallons.			Gallons.	
1874 . . .	780,000	32,000	..	24·5	.. ..
1875 . . .	790,000	36,200	..	22·0	.. ..
1876 . . .	830,000	40,000	..	20·5	.. ..
1877 . . .	840,000	43,500	..	19·5	.. ..
1878 . . .	900,000	46,800	..	19·0	.. ..
1879 . . .	980,000	53,400	..	18·5	.. ..
1880 . . .	1,050,000	63,250	..	16·5	.. ..
1881 . . .	1,160,000	70,000	..	16·5	.. ..
1882 . . .	1,210,000	71,000	..	17·0	.. ..
1883 . . .	1,360,000	73,100	..	18·5	.. ..
1884 . . .	2,270,000	77,000	..	29·5	New engines brought into use.
1885 . . .	2,500,000	82,500	..	30·5	.. ..
1886 . . .	2,950,000	88,500	..	33·0	.. ..
1887 . . .	3,030,000	101,300	..	30·0	New pipes brought into use.
1888 . . .	3,710,000	132,000	..	28·0	.. ..
1889 . . .	4,200,000	151,000	..	28·0	.. ..
1890 . . .	5,700,000	170,000	..	34·0	Sewering of houses commenced.
1891 . . .	7,900,000	190,000	20	41·5	.. ..
1892 . . .	10,650,000	239,000	40	44·5	.. ..
1893 . . .	13,900,000	284,000	60	49·0	Exceptionally dry year.
1894 . . .	16,400,000	321,000	70	52·0	.. ..

APPENDIX IV.

STATISTICS OF POPULATION AND DEATH-RATE IN THE CITY OF BUENOS AYRES (EXCLUSIVE OF THE SUBURBS).

	1887.	1893.
Population at end of year	408,337	540,337
Percentage of population using sewers at end of year	Nil	35
Deaths during year	12,938	13,073
Number of deaths per 1,000 from all causes . . .	32·0	24·3
„ „ from typhoid fever	0·675	0·360

APPENDIX V.

COMPARISON OF THE DEATH-RATE FROM THE PRINCIPAL INFECTIOUS DISEASES FOR SEVEN YEARS, 1888–94.

Year.	Proportion of Population using the Sewers. Mean for the Year.	Small-pox.	Diphtheria.	Typhoid Fever.
	Per Cent.	Per 1,000.	Per 1,000.	Per 1,000.
1888 . .	Nil	1·56	3·09	0·85
1889 . .	Nil	0·28	1·59	0·91
1890 . .	Nil	4·20	1·92	1·18
1891 . .	8	1·14	1·18	0·79
1892 . .	20	0·0055	1·08	0·39
1893 . .	30	0·0275	1·14	0·36
1894 . .	40	0·0055	0·75	0·36

Discussion.

ajamin Sir BENJAMIN BAKER, President, said that many Papers on water-works and on sewerage works had been brought before the Institution, but that was the first occasion on which a Paper had been read dealing with the complete sanitary works of a city of the great importance of Buenos Ayres. The Author had had a unique opportunity, and had worthily taken advantage of it. It would be evident to those members who had read or even glanced through the Paper that the abstract which they had just heard read was in reality little more than a table of its contents. He had much pleasure in asking the members to accord a very hearty vote of thanks to the Author for the valuable contribution which he had made to the Proceedings of the Institution.

. R. C. sons. The Hon. R. C. PARSONS observed that since the preparation of the Paper the figures given in it as to the consumption of water per head in Buenos Ayres had been reduced from 58 gallons to 54 gallons, and he could not help thinking that this consumption would be further reduced, as the regulations became more perfect. Again, the population, which was given as 600,000, had now reached 680,451. That was the population of the total municipal area of Buenos Ayres, which extended beyond the area shown in Fig. 1, Plate 1, and was the federation of a number of townships together with Buenos Ayres, under the Mayor of the city. The death rates given in Appendixes IV and V were calculated upon the population of 618,685. With regard to the districts shown in Fig. 1, Plate 1, the population was now 570,000 instead of 560,000, and of that number about 375,000 inhabited houses supplied with water, and about 300,000 those connected with the sewers. He was able to give from the recent returns some additional figures with reference to Appendix V. During the year 1895, up to October, the portion of the population using the sewers amounted to 53 per cent. instead of 40 per cent. Small-pox had increased; there appeared to have been an epidemic of this disease raging in Buenos Ayres during the year, not nearly as severe, however, as that in 1890, but the mortality had been 0·45 per 1,000 instead of only 0·0053 in 1895. Diphtheria, which was always a measure of the improvement of the sanitary condition of the town, had been reduced from 0·75 to 0·63, in addition to the reduction which had already been made by the use of the

sewers. Typhoid fever had remained the same, viz., 0·36 per thousand. Hon. R. C. Parsons.

Mr. R. J. Neild had, with some interruptions, resided in the city of Buenos Ayres for twenty years, his first visit having been in 1866, thirty years ago. He might, therefore, possibly be able to say something about the local circumstances, which would throw not an uninteresting light on those great and important works. When he first went to Buenos Ayres, the population was about 170,000, and, according to the last census, it now amounted to 700,000. Not only had that almost unheard-of increase taken place, but during the whole of the time there had been a succession of changes in the political constitution, and the social and commercial conditions of the people, which was almost without precedent in any country in the world, with the exception perhaps of the United States. The result of the constant change in that cosmopolitan country had been that, on more than one occasion, money which was intended to be devoted to the purposes of the works had been diverted from it through political changes, wars, epidemics and the like, and a delay had occurred which must have been as unsatisfactory to the subscribers of the loans for carrying out the works as to the engineers who were charged with the spending of the money. The extension of the town had been of a character that it was very difficult to explain. When he first knew it, four years before the epidemic of 1871, which had been the cause of the works being first conceived, the townships of Belgrano and Flores, now included in the capital of the Republic, were distant villages rarely visited, and certainly were not used for residence, by any number of the population. So great had been the progress of building that those outlying townships were now merged with the capital, and many rows of fashionable villa residences connected them with Buenos Ayres itself. The ideas of the people had also undergone many changes, but no changes had occurred up to the present time such as to teach the people the habit of paying the imposts which the maintenance of such costly works necessitated. Works of that sort were often compared with similar works in England; but in Buenos Ayres the population was composed of almost more foreigners than natives, every kind of nationality, speaking every kind of language and having all kinds of customs, and there was great difficulty in collecting the taxes and carrying on extensive works with regularity. He considered that the Argentine Republic was an example to the whole of South America for the wonderfully liberal views which it held, and the manner in which, with many trips and falls, the Mr. Neild

Neild. people had adhered to their purpose, and carried their improvements into operation. He trusted the few words he had uttered would enable the members to see that in forming a judgment of the works, they must not be guided entirely by the criterion formed from experience in England. The cost of the works, also, had been to a great extent in gold, for material imported from England. The wages had been paid in the equivalent of gold, and during the time the currency of the country had so depreciated that the dollar, which at the beginning of the works was worth 4*s.* 2*d.*, was now only worth 1*s.* 3*d.*; so that the raising of the necessary taxes to pay the interest on that money was very arduous.

Hawk- Mr. J. C. HAWKSHAW had paid several visits to Buenos Ayres during the last ten years, and would point out how the Port works, which had been designed by and executed under the direction of his firm, had affected the drainage. A large area of the foreshore, about 900 acres in extent, had been reclaimed by the construction of a sea-wall, 3½ miles in length, extending along the frontage of the city. Within this area a chain of docks had been built, closed by gates at each end, so that a constant level could be maintained in the water within them. This precaution was necessary, because the level of the water in the River Plate, which was here some 30 miles wide, was liable to great fluctuations during gales. Since some of the docks had been open for traffic, the level of the water in the river had fallen on one occasion to 8 feet below zero (low-water spring-tides), leaving only 13 feet of water on the sill of the locks. The storm-water culverts discharged on to the foreshore along the old river margin, the storm-waters flowing behind the docks in an open channel, and discharging at the northern end through a temporary outlet in the sea-wall into the River Plate. The permanent intercepting culvert which was required to replace the open channel, had not yet been begun. It might be inferred from the Author's remark (p. 31) that this delay in constructing the intercepting culvert was caused by the Port works. Such, however, was by no means the case, but the contrary. The intercepting drain could have been begun five or six years ago, soon after the first dock was constructed, and could have been extended as the docks proceeded; and expenditure on the Port works for temporary expedients would have thereby been saved. The Port works reclamation could not be completed, and much of the land could not be made available for building until the intercepting sewer was made. Those, however, who knew the surrounding conditions would be best able to realize the

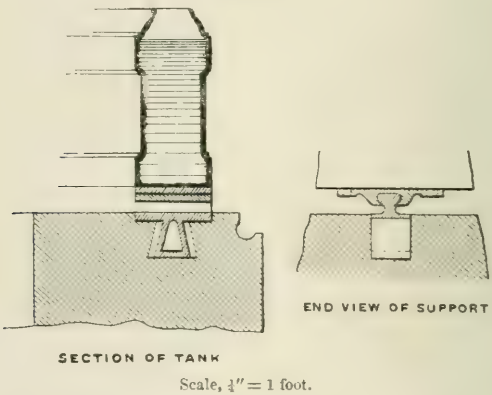
difficulties to be encountered in carrying out the works described in the Paper. The streets and side-paths were somewhat narrow; and although the rainfall of the year was not very great, there were heavy downpours at times. He had seen one of the principal streets, with a stream of water flowing down it the full width of the roadway, and even over the pavements. Mr. Hawshaw.

Mr. Alex. R. Binnie observed that the members had not often the privilege or opportunity of receiving a Paper giving an account of a work undertaken and completely carried out. In a country like England which had been civilized for certainly 300 years, the works partook more or less of additions to previous work; but in the Paper there was described what was most valuable, especially to the younger members of the Institution, a large work, well designed by a master of their profession, and carried out with perfect success. The striking fact about the Paper was that the whole of the works had to be constructed in a country which produced no stone, and where sand had to be brought from a considerable distance. When the difficulties and limitations which such natural obstacles would always impose were considered, it would be seen at once that new circumstances arose calling for great skill. The Paper dealt with works in a sub-tropical climate, where two conditions had to be met—the average daily discharge of the sewage, dealing at the same time with the possibility, at intermittent intervals, of a truly tropical rainfall. He was glad to see that in those works—not for the first time perhaps—a systematic attempt had been made to deal with the possible arising of bad smells from drains and sewers, which of necessity must be made of much larger capacity than that of the average flow of the sewage. In a tropical country, that must always prove one of the great difficulties with water-carried sewage. Perfect ventilation, which had been applied with so much success to house-drainage, had been applied by Mr. Bateman to the public sewers, and on exactly the same lines. It was now held as an axiom of house-drainage that all internal drains should be free from pressure, and have a free communication with the atmosphere. In the works described the public sewers were placed under exactly the same treatment. Shafts were carried up for ventilating the sewers without the necessity of resorting to the crude methods which were often adopted of ventilating at the level of the street. From what he had seen in England and in India he believed that was the proper solution of the difficulty. If sufficient ventilation was afforded a great step would be made in the treatment of town sewage. In reading the account of the reservoir constructed Mr. Binni

Binnie. in the peculiar manner described, with all the elaborate precautions taken to prevent rupture of the structure owing to unequal expansion and contraction, due to changes of temperature, he thought that those precautions were useful in another way in preserving the whole structure when they, in common with the whole system, were subject to the severest trial to which any works could be subjected, viz., shocks of earthquake. Their having passed through such an ordeal with success was in itself good proof that the works were well designed and executed.

Davey. Mr. HENRY DAVEY thought some particulars of the cost of working would be interesting. The filters were stated to work at a percolation rate of 6 inches per hour, and the water contained a very large amount of suspended matter. He imagined that the

Figs. 52.



filters required very frequent cleaning; particulars of the mode, the frequency, and the cost of cleansing the filters, would form an interesting addition to the Paper. As to the method employed to counteract the effects of expansion and contraction in the large reservoir, he had some time ago to support an annular tank, of 22 feet outside diameter, on the top of a tower, where it was exposed to the sun's rays and to wind-pressure. The problem was how best to support the tank to admit of free expansion and still resist wind-pressure. This had been solved in the manner shown in *Figs. 52.* The points of support were constructed like the slide-rest of a lathe, and were arranged radially, so that the tank was free to move, at any point in its circumference, towards or from the centre. The material used, phosphor-bronze, was non-corrosive, so that the tank was not of very great weight, and

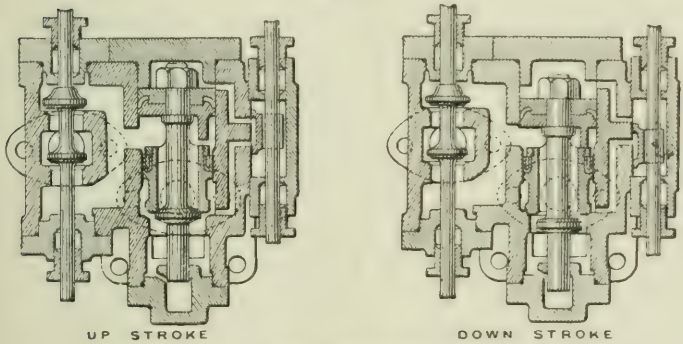
the question of rust did not enter into the problem. In a plane surface, fixed at one point, any point displaced by expansion moved radially from the fixed point, so that a cylindrical joint, or knuckle-joint, instead of a ball-and-socket joint, might be employed. The knuckle-joint was very easily and inexpensively constructed as compared with the ball-and-socket joint, and gave a better bearing surface, and steel facings could then be introduced. If instead of a ball-and-socket joint there had been a knuckle-joint, the axis of which was placed at right angles to a radius drawn from the fixed point to the point of support, it would have answered the same purpose. Although, as the Author had said, it answered its purpose admirably, he thought the ball-and-socket joint an expensive one.

Mr. Dav

Mr. Von Lengerke regretted that the Author had not given more

Mr. Len

Figs. 53.

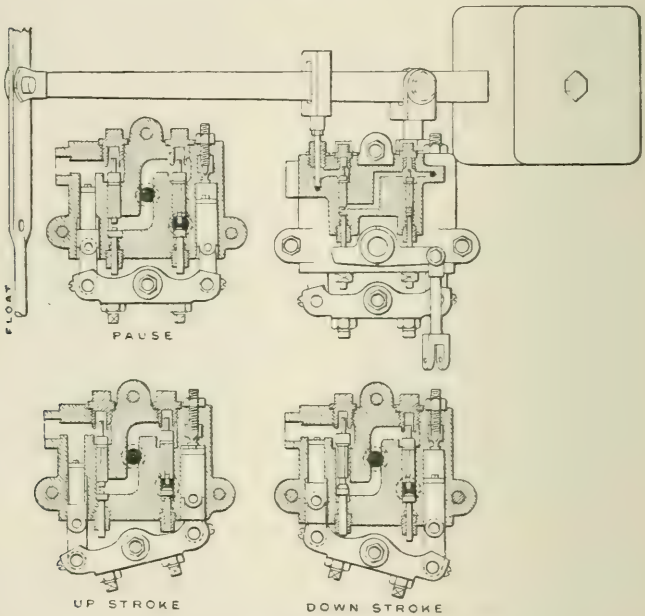


Scale, 1 inch = 1 foot.

information as to the details of the valve-gear of the hydraulic sewage-pumps. A sewage-pump had not only to comply with the conditions laid down by the Author at p. 43, but it also had to work noiselessly, otherwise it was a great source of trouble. He had been resident engineer at the Esher Sewerage Works under Mr. Baldwin Latham, which had been the first extensive application of hydraulic power to sewage-pumping carried out in this country. There had been at first some difficulty in getting the machinery to work automatically and noiselessly, and also without serious leakage, but those difficulties had been eventually overcome. The valves originally supplied to the Esher pumps were shown in *Figs. 53.* They were of a well-known type, and had been used for similar purposes in coal-mines and other places, but they certainly did not work well at Esher. The automatic valve to enable the

ngerke. machine to remain at rest until it was required to come into action was a double-beat valve actuated by a float. It had given much trouble, and could not be maintained watertight for many days together. He had concluded that the double-beat valve could not perform the very important work imposed upon it of controlling the sewage-pump. The main valves were in the centre of the valve-box; the exhaust-valve was annular, and the pressure-valve rose against it, both being actuated by the piston

Figs. 54.



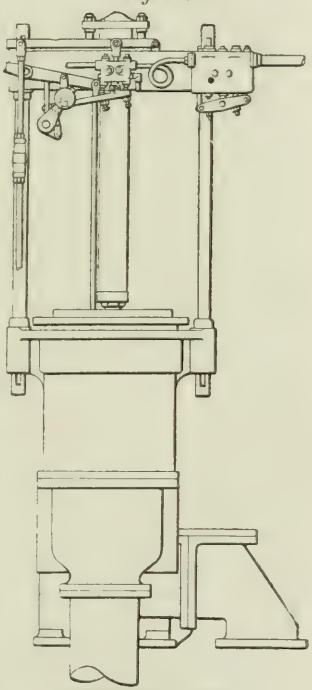
Scale, 1 inch=1 foot.

at the top. The little slide-valve on the right-hand side was actuated by tappets, and allowed exhaust or pressure on the upper surface of the piston to move the valves either one way or the other. In action one of these valves lifted the other; consequently no sooner had the engine pumped to one end of the stroke than it was immediately started in the reverse direction. That arrangement was supposed to have the advantage of producing a uniform flow in the hydraulic main, but it assumed that the pumping stroke was uniform. On the Esher pumps, owing possibly to the very large flap-valves, the pump started its stroke at a very high speed, in fact it went off with what might be described as a

kick and a jump. There was a loud report as the suction-valve closed, followed by another from the delivery-valve, and the working was very noisy and unsatisfactory. The leakage had also been a source of trouble, and was largely attributable to the little slide-valve. After considerable trouble had been taken in endeavouring to get the valves to comply with the specified conditions, Mr. Baldwin Latham had decided that the valves shown in *Figs. 54* should be substituted. The valves to admit the water were perfectly simple check-valves, closed by pressure, and instead of the piston above there were two plungers, one having twice the area of the other. The larger plunger was controlled by tappet-valves, taking the place of the slide-valve, and when the water was exhausted from it thevalve-gear took the position shown in the lower left-hand *Fig.*; when pressure was applied to the large plunger it moved into the reverse position. By these valves the difficulty of leakage had been overcome, but there was still the question of silent working, and that had been attained by throttling the supply of water to the large plunger, so that as the little engine made its strokes it travelled gently from side to side. The lifting plugs were shaped so that there was an interval between the closing of one valve and the opening of the other, to produce a pause at each end of the stroke, enabling the clacks to close silently and without slip. As to automatic action, instead of the float-valve being on the main supply-pipe of the engine, where it must be of considerable size, it had been placed on the little supply passing to the subsidiary piston or subsidiary engine. The float-valve had thus been rendered very simple, was easily replaced, and had the effect of always stopping the engine at the end of the stroke. When pumps for Margate, *Fig. 55*, had been designed somewhat later, the float-valve had been dispensed with. Automatic action was secured by causing the float to throw out of action the tappet-lever, which

Mr. Lenge

Fig. 55.



Scale, $\frac{1}{8}$ inch = 1 foot.

Mr. Lengerke. acted on the two tappet-valves. The valve-gear he had described had been designed by Mr. Baldwin Latham, Mr. Arthur Rigg, and himself; and it overcame the difficulties of automatically working sewage-pumps by hydraulic power.

Mr. Davey. Mr. DAVEY remarked that the valve shown in *Fig. 53* was his.

The President. The PRESIDENT: That was the one that had failed?

Mr. Davey. Mr. DAVEY said it was according to Mr. Lengerke's statement. It ought also to have been said that the one claimed as a success by Mr. Lengerke was an invention of Mr. Baldwin Latham and Mr. Lengerke. In the first place the valve shown in *Fig. 53* was in use in, perhaps, over 1,000 hydraulic engines, and was working perfectly satisfactorily. Engines had been constructed for the last fourteen or fifteen years with that valve, and it was preferable to the small valve *Figs. 54* which had to be kept down with springs that broke about five or six times a week. The valve would not drop of itself; it was not much heavier than a penny piece. The Esher valves had springs behind them for purposes of experiment, and he believed they had been retained, for if they had not, their efficiency would be impaired by the smallest amount of dirt. With regard to the automatic action of the valve, the double-beat throttle-valve was not intended to stop the pump. It was not his intention that it should stop the pump suddenly, and start it suddenly; but that when sewage was coming at a lower rate, the pump should work at a lower rate, and the method described by Mr. Lengerke of throwing out of gear the tappet-rod actuating the subsidiary valve was obviously applicable in the one case as well as in the other, so that if Mr. Lengerke's intention was not to use his own valve but to use his (Mr. Davey's) with such alterations as would satisfy him, he might have applied that to the original valve as well as to have swept the thing away and apply it to something altogether new. The tappet-rod was the same; in fact, there were many mechanical solutions of the problem.

Mr. Latham. Mr. BALDWIN LATHAM was glad to find that the Author had adopted the hydraulic system for dealing with this low-lying district of Buenos Ayres. He had no hesitation in saying that in future it would be universally adopted by all engineers who gave careful study to the question. He would like to know something as to the efficiency of the hydraulic machinery. No information was given in the Paper as to the relation between the power employed and the work performed—a point upon which every engineer desired to have most explicit information. He had studied this question, nearly ten years ago, of introducing the hydraulic

system for pumping sewage, believing both from a sanitary and economical point of view that it was the proper system to be used. In work he had carried out he had taken care as far as possible to determine the efficiency. At Margate there had been very great difficulty in arriving at it, because the Corporation insisted on placing the station from which the power was generated attached to the waterworks at Tivoli. As those waterworks were always in use for supplying water to the town, it was very difficult to discriminate as to the amount of fuel used for pumping the water-supply and that used for hydraulic transmission of power. There were times, but they were rare, when there was such an abundance of water at Margate that the waterworks at the Dane had kept the town supplied, and it had been possible, perhaps for a month together, to work that machinery and to determine with accuracy the cost of pumping. There were four hydraulic stations at Margate, three of which were used for the purpose of dealing with the sewage proper of the town, and a fourth which came into operation at a time when a heavy storm occurred coincident with a very high tide. Under those conditions Margate used formerly to be flooded, and, as in all the low-level districts the separate system had been adopted, a station had been constructed on the surface-water system of drainage containing two of these hydraulic pumps, and so soon as the surface-water rose to a certain level it overflowed into a chamber, raised a float, and started one or both machines to work, as the case might be. It was curious that although these engines had been erected seven or eight years, they had not more than half-a-dozen times in that period been actually brought to work, showing how rare the occasions were when there were heavy rains coincident with high tide. It was, however, a matter of chance, and might have been the reverse. In the three other cases, the average lift at the three stations was 33 feet, and taking labour, fuel, oil, repairs, renewals, and everything into consideration, it cost $\frac{3}{5}d.$ per 1,000 gallons to pump the sewage by this method of transmission of power—by no means an extravagant sum having regard to the cost of pumping sewage in many districts, even around London, where steam-power was used direct and the actual efficiency was a little more than 50 per cent. As to what had been said with regard to Esher, he could only add that Mr. Davey had for many months the opportunity of making his machines as perfect as possible, and that ultimately his firm had left the machines in an imperfect state, when he (Mr. Baldwin Latham) was called upon to advise what means could be adopted to effect a remedy. That remedy had been accomplished in the

Mr. Latham.

Mr. Latham. way that Mr. Lengerke had described. At Margate, one of the original machines had been erected under Mr. Davey's auspices, and was found to behave itself in exactly the same way as those at Esher; it had therefore been superseded by the arrangement of valves which had been described by Mr. Lengerke.

Mr. Davey. Mr. DAVEY said that the engine referred to by Mr. Latham had not that particular valve; it had valves of another kind.

Mr. Latham. Mr. BALDWIN LATHAM said whatever its kind, it was neither automatic nor noiseless. The result was that he had been called upon to deal with the matter. With reference to the scheme delineated by the Author, he thought that the proper system had been adopted, in dealing with the pumping of sewage by the use of high-pressure water, one advantage of which was, that it could afterwards be used for other purposes. For instance, at Margate, where there was a pressure of 700 lbs. per square inch, it was still economical to lead the waste water from the hydraulic engine to a considerable distance from the machinery, and to discharge into flushing-tanks, making use of the water afterwards for the purpose of flushing the sewers. At Esher it had cost about 6*d.* per 1,000 gallons to pump high-pressure water which was after use in the hydraulic engines delivered at an altitude of nearly 70 feet above the hydraulic lifting-machinery, where it was delivered at the head of all the sewers, and was applied to the purposes of flushing; whereas if that water had to be bought from the water company for flushing purposes, it would have cost 1*s.* 3*d.* per 1,000 gallons. In the case of Friern Barnet, the cost of transmission vanished; the value of the water saved by not having to purchase water for flushing, more than paid the whole cost of the transmission of power. The result would be the same in a work of that magnitude. So great was the pressure—800 lbs. per square inch—that water could be conveyed from the hydraulic engines, stored in the automatic flushing-tanks, and used for the purpose of flushing the various branch sewers. In cases where excessive rainfalls had to be dealt with, it was contrary to his practice to carry out a combined system of sewerage, admitting all the rainfall and the sewage to the same sewers. It was mentioned in the Paper that at times the rainfall was as much as 4 inches per hour, and that 9 inches a day was not uncommon. That resembled the tropical falls of Bombay and other Indian cities, and in those cases he had always held it to be absolutely necessary that the rain water should be kept distinct from the sewers. In the case of Buenos Ayres it seemed of paramount importance that that should be observed. The outfall sewer was carried 12 miles down the river

ostensibly for the purpose of preventing the sewage from being brought back to the source of water-supply. The water-supply as shown in Fig. 1, Plate 1, was an intake near point G, which did not appear to be more than 2 miles or 3 miles above the city. The effect, therefore, of combining rainfall and sewage was that whenever there was a very heavy rain a large portion of the mixed sewage and rain would be discharged immediately opposite the city, and therefore there would be a liability, as it appeared, of the dilute sewage, which was as much a danger as any other sewage, being carried back to the intake. If it was necessary to carry the sewage 12 miles below the city, in order to protect the intake for the waterworks, it would appear essential that a complete system of sewerage should have been adopted, so that no sewage should ever have been allowed to enter the river at a point nearer than 12 miles from the city. Mr. Latham.

Mr. E. B. Ellington had been largely responsible for the designs of the hydraulic machinery described by the Author. The sewage-pumps were worked by slide-valves; and the tappet which controlled them worked a small valve as shown in *Figs. 54* of the Esher sewage-pump. The main slide-valves were controlled by hydraulic plungers worked by the small valves. The floats were connected to separate small slide-valves controlled by hydraulic plunger plug-valves, which started and stopped the pumps. Ordinary screw-down stop-valves were also fixed to the service-pipes. The easy working of the pumps to prevent noise or shock had been attained in precisely the same way as had been indicated by Mr. Lengerke; there was a small controlling-valve which was adjusted by hand in the passage leading from the small valve to the main valve. The speed of the main valve could be controlled so that any amount of pause could be given at the end of the stroke. These pumps had been first introduced by himself in connection with hydraulic-power works in London, and were erected at Millbank pumping-station in 1887, where the quiet working of valves controlled in that way could be seen. He believed it was the successful working of these pumps in London which had induced the Author to adopt this particular system. These pumps were in use at the other pumping-stations of the London Hydraulic Power Company, in fact, all the water that came from the river and the docks was pumped by them automatically. The pumping continued day and night, and there was no noise, shock, or trouble in any way. The details to make them suitable for sewage were somewhat varied, but essentially they were the same in principle. The pumps working in London had to deliver Mr. Ellington.

Mr. Ellington. at 70 feet to 80 feet head, and gave an efficiency of about 75 per cent. The efficiency of the pumps at Buenos Ayres was a good deal less than that, owing to the very low head at which they had to work—in some cases only about 10 feet or 12 feet, and the distance from the pumping-station was considerable, sometimes more than 3 miles. At the time the experiments were made there were no houses connected with the sewers in that district. The machinery which had just been erected had to be tried by admitting water into the sewers, so that he had no particulars as to what they would do under actual sewage discharge. The average efficiency of the Buenos Ayres pumps was about 40 per cent. of the indicated power of the engines at the central station. Considering all the special circumstances, 40 per cent. was quite as high an efficiency as could be expected, and would compare favourably with other installations.

Prof. Robinson. Professor HENRY ROBINSON asked whether the Author could give any information with regard to the filtration contemplated at the early stages of this work. The filtration of water of the River Plate had been experimented upon in 1878 by Mr. George Higgin,[1] who had come to the conclusion that the ordinary method of sand filtration would not succeed in clarifying it. In describing the water as delivered, the Author had said, "The results of numerous experiments, however, showed that in order to provide an adequate supply of drinking-water to the city, at a reasonable expense, fine-sand filters were the most satisfactory; and although after passing through such a medium, the water remains slightly turbid, it is not found to be injurious to health." That could scarcely be considered a very high standard for an ideal water, and although he did not wish to suggest it was not an excellent water, Mr. Higgin, in the Paper he referred to, had said that the finely comminuted clay which gave that water its distinct yellow colour was incapable of being removed by ordinary filter paper in the laboratory; and after his experiment he said that a perfect filter was made at last by using engine-cinders, first washed so as to free them from the fire-powder, and then pulverised. Referring to that Paper, in the light of what Mr. Bateman had afterwards decided, he could not help feeling that what he had settled as the right system to adopt must be taken as the best under the circumstances. The result of Mr. Higgin's experiment was conclusive, and the opinion he had expressed in his communication was that a filter made on that basis would not be more expensive than an ordinary

[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 272.

sand-filter. It would be interesting to know whether the Author had any information upon that point. With reference to drainage, the Author had referred to the flush of the cisterns in houses as being 2 gallons. It would be well to bear in mind that at the present time the matter was under the consideration of the Local Government Board with a view to deciding whether that flush was sufficient. He had been engaged upon the subject during the past year, and the view that he had taken was that a 2-gallon flush was insufficient in England, and it would be more so in Buenos Ayres. If the Local Government Board came to the conclusion that a 2-gallon flush was insufficient, the Author would most likely advise the authorities in Buenos Ayres to take some measures to prevent the 2-gallon flush being employed as the ascertained flush of the future. At a recent inquiry held at Southend, he had advised the Corporation to obtain from the Water Company a larger flush than 2 gallons, and a 2½-gallon flush had been agreed to. With reference to that inquiry, information had been obtained from fifty-three towns as to the flush employed, and he was surprised to find that in thirty-four a larger flush was used than 2 gallons; in twenty-one towns a 3-gallon flush was used, and in four towns a 2½-gallon flush, so that out of fifty-three towns more than half had the larger flush. Prof. Robinson.

Mr. Arthur Rigg had designed and made one of the Margate pumps, *Fig. 55*. The sewage-wells were 9 feet in diameter, and contained two pumps, 20 inches in diameter with a stroke of 3 feet, worked by hydraulic engines, like those at Buenos Ayres. He wished to contrast the pumps used at Buenos Ayres and Margate respectively as to the conditions under which they were working, and to show that while the former might be very good for some purposes, it would not do for the purposes which he had considered to be essential for Margate. It was a great mistake to treat sewage as if it was water. It was a great deal heavier than water, and it required more power to work it. The Buenos Ayres pump, shown in Figs. 49, 50 and 51, had wells 13 feet in diameter, and was perfectly flat at the bottom. That appeared to be a bad arrangement, because the sewage would naturally lie all over the bottom, and not run into a little hole where it could be taken out. In the Margate pumps the two suction-pipes were placed in the centre of the well, which was bow-shaped underneath, so that all the sewage was drawn out. There was no double float at Margate, as there was in Mr. Ellington's arrangement, because directly the sewage was sufficient to work the float it started the pump, and the well was emptied. As far as he Mr. Rigg.

Mr. Rigg. could understand from the plans, there must be a large amount of sewage remaining in the well, until it arrived at a point when it reached the upper float. The pump shown in Fig. 51 was not able to suck to a great height. The pump plunger having a 3-foot stroke, the capacity of the clearance space in the pump amounted to about 128 per cent., which was very high indeed. With a 4-foot stroke it was 71 per cent., which was more than sufficient. His own pump, *Fig. 55*, had 53 per cent. clearance. The point was very important, because in these deep wells the object was to keep the pump as far above the sewage as possible. A pump with a large clearance would not suck to great heights; the consequence was that the one pump would suck well whilst the other would not. The same remark might be applied to the waterworks pumps, a section of which was shown in Fig. 23, Plate 2. The waterworks pumps in that particular case had the same evil—they would not suck very high; and they had also, as shown by Fig. 19, a section vessel on one side which was wrongly arranged. The large flap-valves on the sewage-pumps were very noisy, and there was a very elaborate system of buffer-springs upon the rods to prevent any accident happening. He could quite believe, as Mr. Ellington said, that the pump, as a rule, worked quietly, but something might go wrong, and then the buffer would be very useful. The pump at Margate was specially arranged to give ease of access for repairs. The Margate well had a large area for the attendants to stand upon, and the pumps were placed one on each side; the area was covered with a platform so that the men could move about with ease. If there was anything wrong with one of the sewage-pump valves it could be drawn out. They were not large single valves, but four small valves for suction and four for delivery. A necessary feature of a sewage-pump was that the delivery should always be downwards and never upwards, because in the latter case the sewage settled in the pump and everything went wrong. If it was made to flow down the pump it emptied itself every time. As far as he knew there was not more than the average amount of trouble with those valves. There was also in his pump a discharge-valve below which could be opened from above to empty the well. He had seen sewage-pumps in which the lid of the suction-valve had to be raised to let the sewage out. The valves of the hydraulic engine were the same, as to their general principle, as he had used for many years with his hydraulic rotative engine for altering the stroke; and, for that particular arrangement also, they worked extremely well. The Buenos Ayres hydraulic engines, shown in Fig. 51, appeared

to be made partly of iron, probably cast-iron. He thought it was the greatest mistake to use anything but gun-metal in hydraulic engines. Iron would rust and give trouble, and the use of gun-metal for the hydraulic engines would not have entailed much additional expense. He thought the engineers who carried out the work must have had great difficulties to contend with; he could not understand the statement, however, of the Author, on p. 39, that exceptionally high tides occurred at frequent intervals. Mr. Rigg.

Mr. W. R. Smith observed that engineers appeared to have implicit faith in the efficiency of a water-seal trap when combined with so-called inlet and outlet ventilating-pipes on the sewers and drains to prevent the escape of sewage gas into houses. It was stated by the Author that the closets were all "flush-out," which of course indicated that the only defence against the escape of sewage-gas into the houses was a water-seal of about 1 inch head. In addition to that there was a water-seal trap immediately outside the house, also ventilated, but these were two separate water-seals and might be considered separately. The water-seal might be considered efficient in normal states of the atmosphere. The water constituting the seal was always in contact with sewage-gas on one side of it however, and consequently became putrid, even in England, in three or four hours and required to be renewed frequently to be innocuous. In a tropical climate the water would become a source of nuisance in a much shorter time. But the conditions in abnormal states of the atmosphere must also be taken into account, for in Buenos Ayres there were occasional pamperos with velocities reaching 100 miles per hour. Under such circumstances the wind could not be regarded as blowing in at the so-called "inlet" ventilator at a high velocity and out at the so-called "outlet" at an equally high velocity. He should rather look upon the atmosphere as a deep ocean in a state of agitation, the greatest agitation taking place next to the earth. Considering that vast volume of air about four, five or six thousand feet deep, and contrasting it with the height of an ordinary dwelling-house, it was difficult to see how that high wind, that violent agitation of the atmosphere, could discriminate between the so-called "outlet" and "inlet" pipes. There was a non-agitated volume in the house at the bottom of the ocean, and a great volume of violently agitated air seeking by every possible aperture to get into the non-agitated portion, and that was the problem to be dealt with. It was impossible, so far as he could see, to count upon one aperture being an inlet ventilator and another an outlet. Considering that all there was to resist the combined action of the two currents Mr. Smith.

Mr. Smith. of air entering by the so-called inlet and outlet vents at that high velocity was a water-seal of, say, ½ oz. pressure on the square inch, and that the pressure increased as the square of the velocity, the 1-inch water-seal was quite unreliable. The wind velocity corresponding to a head of 1 inch of water was 30 miles or 32 miles an hour, while the head equivalent to a wind velocity of 100 miles an hour was about 15 inches or a pressure of 7 ozs. per square inch. Two currents due to the higher velocity combined could not possibly be resisted by a water-seal of only 1 inch head. The water-seal appeared to be the principle upon which the flush-out closet had been universally substituted for the older forms of water-closets. The original water-closet, so far as he was aware, was that invented by Bramah, and, notwithstanding the so-called improvements of over a century, the Bramah closet to most engineers would present itself as the only perfect closet, and it was a matter of astonishment that County Councils allowed any other. The Bramah closet had a flap-valve closing from below the basin. The valve itself was a perfectly efficient gas-trap, and above that there were 8 inches head of water. Below it again there was the same 1-inch water-seal of the ordinary gulley trap. Successive improvements of water-closets had been made in the form of the pan-closet, which became a nuisance because it had such a large area to become coated with sewage refuse, then had followed the Shanks plunger with a similar defect, and now these attempts at simplification had been discarded, and "flush-out" closets were used entirely depending upon 1 inch of water-seal. The most important water-seal of all for the sewage system was the constant immersion of the main sewage outfall. At Aberdeen the main sewage outfall was uncovered at every half-tide. For six hours every tide the outfall was exposed to all gales blowing towards the sewage pipe, the highest gales generating a very great pressure, and causing a terrible escape of sewage-gas into the houses in the neighbourhood. He had known many cases of illness and premature death which could be traced to that cause in Aberdeen. The most important of all water-seals was therefore to have the main sewage outfall immersed at all states of the tide. He could not gather from the Paper whether that was the principle adopted at Buenos Ayres.

Mr. Crimp. Mr. W. Santo Crimp remarked, with regard to the principle upon which the City of Buenos Ayres had been drained, that the Author had stated that a system of sewers had been constructed capable of carrying off ¼ inch of rain in twenty-four hours, the amount to be carried off by the intercepting-sewer. That meant

that the sewers would practically carry off about $\frac{1}{100}$ inch per hour. In England the average rate of rainfall was about $\frac{6}{100}$ inch per hour. It would seem, therefore, unless the conditions relating to rainfall were in Buenos Ayres very different to those in England, that the intercepting-sewers were by no means too large. He presumed that the channels shown in the regulating-chamber indicated the means by which the excess volume of rain-water escaped into the storm-water conduit and so into the river. It would be interesting to know the relation which the dry weather sewage-flow bore to the storm-water when the overflows were first brought into operation. The question as to the proper method to be adopted in draining a city of that kind had been raised by Mr. Baldwin Latham. It was an extremely important point, and, having for many years been connected with the London main-drainage system, he had come to the conclusion that for a city closely built over, the combined system was the proper one to adopt. In the case of the separate system, the street-washings, which were necessarily foul, due to the lightest of the rainfalls, would be carried into the river. On the other hand, in the combined system, all these foul street washings, due to light falls of rain, were carried to the outfall works, and in the case of Buenos Ayres they would be discharged into the river many miles below the town. He thought, therefore, that upon the question of principle, the system adopted for the drainage of that city had been the right one. Mr. Crimp.

Mr. T. Hennell observed that the water for the supply of Buenos Ayres had to be passed through a complicated system of settling-ponds and then through another system of filter-beds, and after that, according to the Author, there were difficulties owing to alluvial deposits in the service-reservoir and the main pipes. It appeared at the same time that a large quantity of subsoil water was finding its way through the neighbourhood of the intake into the river, which gave rise to considerable difficulties in constructing the tunnels. He would ask why that naturally filtered water had not been utilized to supply the town? One tunnel, from G to H, Fig. 1, Plate 1, was 1 mile long, and so much water was met with that the contractor was overpowered, and a great deal of difficulty had arisen in getting rid of it. There was another tunnel, 3 miles long, from H to C, and there the difficulty from the water had been so great that the tunnel had to be raised, even at the cost of providing, and working for ever afterwards, a separate pumping-station. This tunnel was raised 22 feet to bring it out of that water. It appeared, without explanation, Mr. Hennell.

Mr. Hennell. that the quantity of water must have been so great as to be very useful for the supply of the town, and that if a tunnel had been made, perhaps not 3 or 4 miles only, but possibly 5 or 6 miles long, parallel with the river, going up the valley away from the town, to intercept the subsoil water, a supply might have been obtained sufficient even for the requirements of the whole area. If so, this supply could have been delivered without any intermediate process direct from the tunnel to the service-reservoir.

Mr. Hawksley. Mr. C. HAWKSLEY wished to express his opinion that a 2-gallon flush was amply sufficient for all purposes when properly applied. The reason why it was sometimes said to be insufficient could generally be traced to one or more of three causes: first, to the water not being brought down with sufficient rapidity from the flushing-cistern into the basin of the water-closet; secondly, to the imperfect construction of the basin of the closet itself; and thirdly, to the very imperfect way in which the drains leading from the water-closet to the public sewer were frequently constructed. When these three points were properly attended to, it was found that a 2-gallon flush was sufficient for all reasonable purposes. He therefore ventured to think Mr. Bateman had exercised a wise discretion in not making the flush larger.

Mr. Parsons. Mr. PARSONS, in reply, with reference to the cost of working of the hydraulic system in Buenos Ayres, thought it would be interesting to ascertain the sequence with which the pumps would work when in use, some would probably work in unison and some alone, and sometimes possibly the whole system might work at the same time. It had hitherto not been possible to make these experiments, in consequence of the small number of houses which were as yet connected with the sewers. He was told that the houses were now being rapidly connected, and he hoped to obtain the results of some satisfactory experiments which he would have pleasure in laying before the Institution. With regard to the cleansing of the filters, they worked consecutively for about three weeks, when a thin coating of very fine alluvial deposit accumulated on the surface. A layer of sand, between $\frac{1}{2}$ inch and 1 inch thick, was then scraped off, washed and replaced on the surface of the filter, after which it would work as well as before. The peculiar arrangement of module shown in Fig. 11 was especially invented for the purpose of regulating the depth of water on the filters and worked exceedingly well. By this means a very much greater head was obtained on the surface of the filter when it became dirty and the water was then forced through it. When it was clean, a smaller depth was

Mr. Parsons.

required, as the water passed through quite easily. The reservoir described in the Paper was very much larger than any reservoir which had yet been made, and he doubted whether the knuckle-joint would meet that case satisfactorily. It would meet the case with regard to the expansion of the floor, no doubt, but there was another question to be considered, viz., the danger of a creeping of the material. It was not clear that the expansion and contraction in those various complicated members would always be equal to one another, and there was a danger of the expansion or contraction from one day to the next accumulating, and, if it did accumulate, the displacement would become very considerable, and not necessarily in the direction of the knuckle-joint. If this did occur, possibly these columns, upon each of which there was a weight of about 450 tons, would become strained beyond their limits of elasticity. For that reason he thought it advisable, although the ball-and-socket joint was slightly more expensive than the knuckle-joint, to adopt it. A question had been asked with reference to the hydraulic valve. In adopting the slide-valve he always had in view the opinion of his late master, Dr. Wm. Anderson, namely, that the best and most enduring valve was the slide-valve. With regard to the silent working of the pump, every pump was thoroughly tested before it left the works of the manufacturers, and the slide-valve fitted, with a "V" groove in the edge, so that the hydraulic pressure did not come suddenly on the plunger. They worked noiselessly, and he could not see why Mr. Baldwin Latham had not adopted a similar valve instead of the complicated one shown in *Figs. 54.* The question of the admission of the rain-fall to the sewers was a very important one, and the gradients of the city and the narrowness of the streets were such that it was found less expensive to adopt this system than to provide a separate one. That had been arranged many years ago, and the separate system which had since been carried out might possibly throw further light on the subject, but that was a question which he could hardly discuss, seeing that it was adopted long before he became connected with these works. With regard to the sewage becoming mixed with the water-supply, as explained in the Paper, exhaustive experiments had been made, and it was found that at the time of heavy rainfall the stream was always down the river. The amount of water flowing into the River Plate was so great as to quite overcome all tidal action. There was therefore no possible danger of sewage being carried up to the inlet of the water-supply. In the experiments of Mr. G. Higgin it had been found that there were several *media* which could be used for filtering the water,

Mr. Parsons. viz., cinders, as Prof. Robinson had mentioned, and also animal charcoal, all of which rendered it perfectly clear. The Chamberland filter, which was of porcelain, would also make the water perfectly clear, but all these methods were expensive, and in the supply of 20,000,000 gallons per day to a town the cost of filtration was a matter of very great importance, and the slight alluvial deposit left in the water was not considered to be injurious to health. It was entirely a question of expense. The water could be cleared absolutely if it was necessary, but up to the present time he had not thought it advisable to recommend the adoption of any of those processes which would entirely clear the water. Attention had been drawn by Mr. Rigg to the height of the suction of the sewage-pump, who also mentioned several points with reference to clearance in the pumps. There was a plunger in the pumps and an absolutely perfect contact of the sewage with the plunger. The question of clearance affecting the efficiency did not enter into the matter. The waterworks pumps also no doubt had a lift on the suction, and it was found that they worked perfectly. As to the high tides occurring at frequent intervals, the wind was the main factor. When it blew from the south there was always a high tide. The diurnal tides in Buenos Ayres were almost invisible; their height depended upon whether the wind was blowing from the south or the north. When it was blowing from the south, tides were high, and when it was blowing from the north, they were proportionately low. The same thing took place in the Baltic, where it was found in St. Petersburg that the tides depended almost entirely upon the wind. With regard to the traps in houses being unsealed, that was a point which had been very carefully considered, and throughout the town the ventilation was so good that wherever a water-closet was connected with the sewers there was a ventilator. The consequence was that the ventilation was such that the seal of the traps was practically never disturbed by the action of the wind. With reference to the ratio of sewage to water at the time of overflow into the intercepting sewer, it was about 3 of sewage to 4 of rain, and when those proportions were reached the overflow began. A question had been raised by Mr. Hennell as to why the town of Buenos Ayres was not supplied with water from the subsoil. The subsoil undoubtedly carried a very large quantity of water, but the water-bearing strata were not very far below the surface. The system adopted for the disposal of the sewage of houses not connected with the sewers was by means of cesspools, as explained in the Paper, and the contents of the cesspools invariably communicated

with the subsoil water; if, therefore, the water was taken from the subsoil, there was always a danger of its being contaminated with sewage. With regard to the proper quantity of flush which Mr. Hawksley and Professor Robinson had alluded to, he thought the amount necessary depended entirely upon the construction of the sewers. If badly constructed, the amount of flush necessary to keep them clean was large; if, on the other hand, they were properly constructed with adequate gradients, then a small quantity only was necessary. In Buenos Ayres he believed a 2-gallon flush was amply sufficient to keep the sewer in proper working order. Mr. Parsons.

Correspondence.

Mr. A. Fairlie Bruce had found, with regard to the subterranean flow of water towards the rivers of the Argentine Republic, that in the province of Santa Fé the same conditions prevailed, there being a general rise in the level at which water stood in the wells as they receded from the Paraná. A considerable supply of clear water had been obtained in several cases by sinking wells in the foreshore at the foot of the Barranca. Its greater hardness was, no doubt, due to the fact that the tosca, through which it had passed, contained a considerable quantity of lime nodules, from which lime was made in some places. As the water which leaked into the tunnel from the Buenos Ayres intake was of perfectly good quality there did not appear to have been any reason for excluding it, the leaks would tend to take up in time if they had not already done so. At Rosario,[1] where, in addition to repairing the existing works, he had carried out an extension of the waterworks, for the Rosario Waterworks Company, the general conditions were similar to those in Buenos Ayres, save that deep water occurred close to the foot of the Barranca; and that the quantity of solid matter in suspension in the water of the Paraná was perhaps somewhat less than in that of the River Plate. There were four settling-ponds, lined with concrete and with no cross walls. The water was pumped into them, and allowed to settle for about forty-eight hours, when it was drawn off by decanting pipes to about 2 feet from the bottom. They required to be washed out about once a month in summer, when the river was high and heavily charged with silt, and about every three months in winter. They worked perfectly satisfactorily, the cost of that which he Mr. Bruce.

[1] Minutes of Proceedings Inst. C.E., vol. cviii. p. 334.

Mr. Bruce. had constructed being only £1 0*s.* 10*d.* per 1,000 gallons of storage. In Rosario the rate of filtration was about 75 gallons per square foot per day, or 6 inches per hour, nearly identical with that adopted at Buenos Ayres. The filtering materials were of about the same thicknesses, but instead of the drains being embedded in the lower stratum, the whole bottom of the filters was laid with bricks set on edge, covered with others placed flat, forming a continuous drain communicating with a central brick culvert, which discharged into regulating wells, whence it flowed to the clear-water reservoir. The head required, when the filters were clean, was between 4 inches and 6 inches; when it exceeded 2 feet 6 inches the filter was changed, as any greater head was found liable to cause the bursting of holes through the sand. About 1 inch of the upper surface was scraped off and removed to the sand-washer. When the total thickness of sand was reduced to 12 inches by successive scraping, the original thickness was restored. Sand which had been used and washed was found to be more efficient than new sand. The cost of cleaning a filter, including sand-washing, was about $\frac{1}{4}$ cent gold per square metre, or 1 cent per 1,000 gallons filtered.

Trouble had been experienced, as described by the Author, from the growth of green slime on the surface of the sand in summer, necessitating changing the filters about every two or three weeks, but as the interest on the cost of roofing the filter beds, as was done at Buenos Ayres, would have exceeded the saving in working expenses by their needing to be cleaned less frequently, it had not been deemed advisable to carry it out. The filters were lined with concrete, made of five parts of broken bricks, three of sand, and one of cement, and cost, including filtering materials, 19*s.* 10*d.* per square yard. There being plenty of good sand and gravel on the islands in the Paraná, it was much more easily obtained than at Buenos Ayres; it was all delivered at the company's jetty, and discharged from the boats by an iron bucket hauled up a wire rope by a steam-winch, at a cost of $0·64 per cubic metre, equal to 1*s.* 3*d.* per cubic yard. The cost of brickwork and concrete at Rosario, owing, no doubt, to their having been carried out by administration instead of by contract, and also to natural advantages, were, as shown in the Table on the following page, much less than at Buenos Ayres. At Rosario the period of maximum consumption in summer was from 4 P.M. to 6 P.M., and amounted to about two-and-a-half times the mean rate, due to the use of hoses in cooling the Patios.

The arrangement of the distribution pipes in Buenos Ayres

seemed unnecessarily complicated, and must tend unduly to reduce the pressure. In Rosario the town was divided into sections three or four squares wide, in each of which was an 8-inch or 10-inch pipe starting from the main, running east and west, and intended to run into a duplicate main round the west and south sides of the town not yet laid. At every square 3-inch pipes were laid, running north and south, communicating at each end with the sub-mains, and having a 3-inch branch, one square long, in each intermediate square, terminating in a hydrant for scouring purposes. All branches were controlled by valves. Air-cocks had not been used in Rosario as the house-services were considered to make sufficient provision for this purpose, and no disadvantage had resulted. Between 8 per cent. and 10 per cent. of the water in Rosario was sold by metre; for the remainder, a conventional charge, or a rate of $3\frac{3}{4}$ per cent. on the rental, was collected. Mr. Bruce.

Cost of Brickwork per Cubic Metre.

	$ gold
350 bricks at $4·4 per 1,000	1·54
¼ cubic metre of sand at $0·64 per cubic metre	0·16
Labour	1·60
1 barrel of cement	4·25
	7·55

equal to £1 2*s.* 6*d.* per cubic yard.

Cost of Concrete per Cubic Metre.

	$ gold
Broken bricks	1·12
Sand	0·24
Labour	0·80
1¼ barrel of cement at $4·25	5·31
	7·47

equal to £1 2*s.* 3*d.* per cubic yard.

For drainage, Rosario was divided into three districts; the principal one was 19 squares in length, and 10 squares in breadth; it was drained by a main sewer, running along Calle Mendoza in the centre of the district of the new oval section, 6 feet 11 inches by 4 feet 7½ inches, lined with 18 inches of brickwork in cement rendered with cement mortar; the gradient was 1 in 500. It discharged flood-water directly into the river down a flight of altar steps; the dry-weather flow was intercepted and carried out beyond extreme low water in a 24-inch pipe. Subsidiary sewers, iron pipes with turned and bored joints, draining five squares each, connected with the main sewer at the manhole at the street intersections; they began at 15 inches

Mr. Bruce. diameter and diminished to 9 inches diameter. Branch sewers, of stoneware pipes 9 inches in diameter, joined them at ventilating manholes at each street crossing; they each drained one square, and started from a flushing-tank at a depth of 1½ metre. The minimum gradient was 1 in 200. The second and third sections were only fifteen squares and nine squares long respectively, and 4 squares wide, and were drained by egg-shaped sewers 5 feet 6 inches by 3 feet 4 inches. To prevent its flowing into the port, the storm-water from the third section was conveyed to the outfall of the second in a double line of 33-inch pipes. The dry-weather flow from both sections was intercepted and conveyed in a 20-inch pipe to the Mendoza outfall. The subsidiary systems were the same as that he had described. The house-connections were all 6 inches in diameter, laid at between 1 in 20 and 1 in 40 to the house line. No ventilating pipes were placed up the fronts of the houses, as at Buenos Ayres, as it was considered that the manholes afforded enough ventilation. When streets were not fully built up, additional connections were left every 10 metres, closed with stoneware stoppers. Where the depth of the sewer exceeded 2 metres, vertical pipes were laid up to 1½ metre below the surface to reduce the depth of trench required for the branches. Gullies, similar to those at Buenos Ayres, but with stoneware traps, were placed at the street intersections, and as at Buenos Ayres have entirely prevented the streets being flooded as they used to be formerly in wet weather.

The main sewers were constructed at depths varying between 60 feet and 30 feet, and were all tunnelled through the tosca, which, in Rosario, rose to within 6½ feet of the surface; no water whatever had been met with, and many of the headings stood unlined for two years, the marks of the pick being as sharp at the end as when first made. The only trouble experienced in their excavation being due to the difficulty of securing efficient ventilation, the ground, especially in the older part of the town, being saturated with fæcal matter, gave off quantities of sewer-gas, causing many cases of blood-poisoning among the workmen; without ventilating-fans candles would not burn in many cases 10 yards from the shafts. Most of the subsidiary sewers had also been laid in headings, shafts for house-connections being sunk every 10 metres or 12 metres.

In Rosario the natural difficulties encountered were much less than in Buenos Ayres, the only troublesome portion of the work being the laying of the intercepting and storm-water pipes which run along the foot of the Barranca, chiefly in reclaimed ground,

where the trenches were liable to be flooded by the river. The breakage in transit amounted to about 1 per cent. in iron, and to about 4 per cent. in stoneware pipes. Mr. Bruce.

Mr. Robert Godfrey considered the Paper of great value to municipal engineers, as in it was shown a system of sewer-ventilation which more nearly approached perfection than any which had hitherto been attempted. He had for some years past contended that every house contributing to the contents of a sewer should also contribute to its ventilation. The model by-laws of the Local Government Board, which were largely adopted in England, did not accept that principle; but, by the regulation insisting on the "intercepting siphon," compelled the sewers to ventilate themselves through the manhole and ventilator covers at the street-level. This was contrary to sound sanitation, and was without doubt the source of more complaint than any other with which a municipal engineer had to deal. The system of house-drainage adopted at Buenos Ayres was most complete, and one which might well be imitated. The inspection-chamber, inserted at all junctions, was a decided advance; and the adoption of the 4-inch pipe for internal drainage was a distinct acknowledgment of the unsoundness of the practice of making drains too large for the flow, as was too general in almost every municipality in England. The minimum gradient of 1 in 40 secured a discharge many times in excess of the quantity of water used per house; and the existence of the intercepting siphon was no longer a source of trouble, as the discharge is into a 6-inch pipe connected to the main sewer. The insertion of a ventilating shaft on the 6-inch pipe on the sewer, at the side of the siphon, completely cut off the sewer from the private drain, and the manhole and ventilator covers were delegated to their proper uses, that of acting as inlets for fresh air instead of outlets for foul air. The dissemination of sewer gas through these pipes 6 feet above the roofs of the houses was undoubtedly the only rational means of reducing the pressure on the aerial contents of the sewer when the liquid contents were suddenly increased by an influx of rain-water. If it was made compulsory in England to adopt the same system of ventilation, there would be an end to the present multitudinous complaints and to the ingenious devices for dealing with sewer air, which had been tried in many cases and had nearly always proved ineffectual. Mr. Godfrey.

The nearest approach to this natural ventilation adopted in England was at Torquay, where a pipe 1 inch in diameter was carried from the sewer side of the siphon up to the roof of each

Mr. Godfrey. house. This was done by a voluntary arrangement, but could not be enforced. The 4-inch pipe adopted at Buenos Ayres was much superior. The valuable figures given in Table 5 proved conclusively that there was no danger to public health from the adoption of this method of sewer ventilation. The modification of the Local Government Board by-law, insisting on the intercepting siphon (without ventilation), would be accompanied by a notable improvement in the public health of the great centres of population throughout the country.

Mr. Nyström. Mr. C. A. B. NYSTRÖMER desired to touch upon a few points as to the development of the works beyond the stage in which they had been described by the Author. In consequence of the rapid growth of Buenos Ayres, and of the great increase which had taken place in the water consumption, the necessity had presented itself, already some years ago, of constructing the extensions which Mr. Bateman had provided for in his scheme. The average daily consumption, which at that time did not reach $\frac{3}{4}$ million gallons, had increased to about 8 millions in 1891, when the Company handed the works back to the Government; and it had since gradually increased to 18,400,000 gallons in the year 1895, having fluctuated between the limits of 25 millions and 14 millions. Accordingly, both engine-houses at the Recoleta pumping-station had been duplicated; the main engines being finished and brought into service in 1893, and the erection of the new intake engines was approaching completion. In order to supply the want of the latter to some extent, it became indispensable to erect temporarily a 24-inch centrifugal pump, which had been in use since 1892 and still did service, raising the water from the intake tunnel to the settling pools. The duplication of the sewage pumping station at Puente Chico was also about to be begun. The existing filters having become altogether insufficient for purifying the great quantities of water consumed, it had been resolved, early in 1893, to construct additional filters and settling reservoirs, on the basis of a total supply of about 20 million gallons. The site chosen for the new settling reservoirs was between the river and the intake station, the pumps of which would now deliver, under constant head, into a chamber constructed alongside the building; from which the water passed into the old or new reservoirs. These latter covered an area of about 24,500 square yards, and were divided into three large compartments and a lateral channel, by means of which any compartment could be isolated for cleansing purposes without affecting the working of the others. Their total capacity was about 14 million gallons; and the water,

guided by the division walls constructed for the purpose, was made to travel a distance of about 3,600 feet, between the inlet and outlet wells, when all the compartments were in use. Ten weirs, the sills of which were placed 6 feet 6 inches below the top water-line, had been provided for regulating the flow of the water and for closing off any portion of the reservoirs. Each weir was supplied with three cast-iron sluices, so made that the water might be drawn from the uppermost or lower layers, according to the season; and all had movable strainers for intercepting floating matter. The cleansing arrangements were similar to those described for the old settling-pools. On account of the greater depth of the weirs, however, the quantity of water which had to run to waste was comparatively small, provision having been made for conveying to the filters most of the water to be drawn off for cleaning any of the compartments. From the outlet chamber, cast-iron mains were laid to the old as well as to the new filters. The pools had to be made chiefly in embankment, and had slopes of 1 to $1\frac{1}{4}$, with double brick lining resting on clay puddle. In order to save space, the ordinary division walls were executed in brickwork and the thicker walls in concrete with brick facings. Mr. Nyström.

The new filters required to be considerably larger than those first constructed, and it was desirable to reduce their cost as far as possible. The system of construction previously adopted had therefore to be somewhat varied, and the pure-water reservoirs below the filters omitted. The new filters consisted of twelve independent compartments, arranged in four groups, and had a total sand area of about 32,150 square yards. The filtering materials were composed of 3 feet of fine sand, supported by successive layers of coarse sand, small and large broken granite, and dry-brick channels, having a total average depth of 2 feet 9 inches. The water was intended to be maintained of a constant depth of $4\frac{1}{2}$ feet over the sand. The side and division walls, having a batter of 1 in 6, were constructed in brickwork and concrete, the former being backed with clay puddle; the floors were also laid on a puddle foundation. The filter-beds were designed to be covered over by light groined arches, resting on square brick piers, and on this covering it was intended to place a layer of earth and turfing. This protection was considered advisable, for keeping the water cool and preventing the rapid germination which took place under the direct rays of the sun, as well as on account of the filters being situated near one of the most heavily worked railways, and

Mr. Nyströmer. exposed to atmospheric contamination. For reasons of economy, however, the covering had not yet been constructed. Each of the twelve compartments was provided with inlet, outlet and cleansing wells; and, after cleaning, could be filled from below with filtered water. From the outlet wells, designed to contain an apparatus for varying the velocity of filtration or maintaining it constant, the water passed through cast-iron pipes into the existing pure-water reservoirs, the capacity of which was with proper care sufficient to receive the additional quantity of water produced by the new filters. Each group of these was provided with three sand-washers and paved platforms for depositing and cleaning the sand. Together with the old filters, the total sand area at present available was about 50,400 square yards. But as the consumption was constantly increasing, in a great measure owing to preventible waste, further filter area would soon be required, if the water was to be satisfactorily purified. The complete clarification of the River Plate water was attended with considerable difficulty, on account of the very fine argillaceous matters it carried in suspension, the amount of which was increased not only by the rains falling on the extensive delta of the Paraná, but also by tides and winds which stirred up the mud in the relatively shallow river. In 1877, Mr. George Higgin made experiments for ascertaining the best means of effecting its filtration, and arrived at some valuable conclusions.[1] He considered that sand alone would not remove the turbid appearance from the water, and that a uniform speed of filtration could not be maintained, although the head were kept constant. By interposing a layer of pounded cinders under the top layer of sand he had, however, been able to render the water perfectly clear and bright, even with high velocity of filtration. Mr. Nyströmer had continued those researches on a larger scale, in 1885 and more recently; many of the experiments having been continued uninterruptedly for months. Several of the substances tried, such as pounded scoria, spongy iron, animal and vegetable charcoals, etc., were found capable of removing completely the opaline colour of the water, and more or less perfectly also the yellowish tinge it retained after having been rendered transparent. The analyses proved that the purification was equally satisfactory in other respects. Unfortunately, the application of these purifying agents on a large scale, as well as the cleansing of the filter, proved very costly. It was likewise found easy to effect an entirely satisfactory

[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 272.

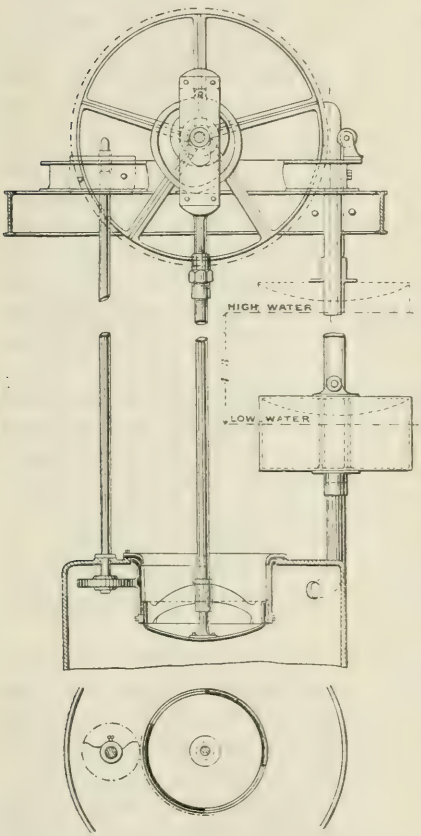
purification of the river water by the use of precipitants, such as ferric sulphate and perchloride, sulphate of alumina, alum and others, as well as by metallic iron. The principal objections to the employment of these substances were their cost, the long time required for the impurities to settle unless the amount of the precipitant was considerably increased, and the speedy obstruction of the filter if used to shorten the process. One of the more important results obtained in the course of those experiments had been that the ordinary filtering sand was quite capable of rendering the River Plate water transparent if the filter was carefully worked. To this end it was requisite that the speed of filtration should in the beginning be almost imperceptible, and be very slowly and gradually increased, avoiding all brusque variations; further that the filter should be charged from below with pure water, in order to avoid subsequent disturbances from rising air bubbles. With similar precautions, the slimy sedimentation of mineral and organic matter which took place on the surface of the sand, rendered the filtration more efficacious, by partially obstructing the interstices of the sand, as it was then thought. Later investigations, by Mr. Piefke [1] and others, had furnished different and probably more correct conclusions as to the action and importance of that layer of impurities for obtaining satisfactory results and for preserving the filtering materials clean. For purifying the River Plate water, the rate of filtration must, however, be smaller than that generally admitted; the descent of the water on the sand should not exceed 3 inches or 4 inches per hour, when the filter was working at its maximum rate. Mr. Nyströmer.

In order to make it possible to maintain a constant rate, the automatic module mentioned by the Author was suggested. But as this apparatus was not well adapted for gradually increasing the speed, another form of regulator had been designed for the new filters. The apparatus, *Figs. 56*, consisted essentially of a float actuating a cam or excentric of such shape that, whatever be the height of water in the pure-water well, it adjusted automatically the size of the outlet openings to maintain a constant discharge. To this end it was made to raise or lower a ring, moving inside the tube which contained those orifices and partially covering these. By means of an outer ring, moving horizontally and capable of adjustment in this direction, it was possible to vary

[1] "Die Principien der Reinwasser Gewinnung vermittelst Filtration," Berlin, 1887; see also Minutes of Proceedings Inst. C.E., vol. cxix. p. 236.

Mr. Nyströmer. simultaneously the length of the orifices and thereby the rate of filtration. Provision was made for keeping the level of water over the sand constant. The new filters and settling reservoirs had been completed since he had retired from the direction of the works, Mr. Charles Anthony, jun., acting as Resident Engineer during their construction.

Figs. 56.



Scale, ½ inch = 1 foot.

APPARATUS FOR REGULATING THE SPEED OF FILTRATION.

The town of Belgrano, situated nearly opposite the Intake tower, Fig. 1, Plate 1, and now forming one of the more important suburbs of Buenos Ayres, had for a number of years been supplied with water from the river. The works, when taken over by the Government early in 1892, were found altogether insufficient for the demand and the quality of the water open to serious apprehensions on account of the close proximity of the intake to the shore and to a small stream which was exposed to frequent contamination. In view of this and of the recurrence of zymotic diseases in the district, he had received instructions to study and report on the works which should be executed. The intake, filters and engines being in very bad condition and the whole establishment subject to inundations, it would have been expensive and injudicious to extend these installations. To continue the town mains to Belgrano also presented some inconveniences. It was therefore proposed to obtain the supply by constructing a semi-artesian well, and the corresponding project had after some delay been carried out. The ordinary

subsoil waters were found at different depths below the surface, according to the height of the ground; but, in the immediate vicinity of populous districts, they could not be accepted as potable, in consequence of the practice of sinking cesspools and drain-wells into this stratum. Lower down, successive water-bearing strata were met with, containing generally brackish water; but at a depth of about 70 feet or 90 feet below low water in the river, a powerful layer of fine sand was found, the thickness of which was stated to be over 75 feet in the neighbourhood of Buenos Ayres. Repeated analyses had proved that the water it contained was of excellent quality, crystalline and very pure, although somewhat harder than the river water. If a bore-hole was sunk into this stratum, the water almost invariably rose above the low-water level in the river, and hence these wells were termed semi-artesian. Wells had been sunk to 250 feet and even 900 feet in depth, and three more water-bearing strata had been found, but of less magnitude and furnishing generally brackish water. A site had been obtained for the pumping station on the eastern margin of the town, and a bore-hole 15 inches in diameter had been sunk to a depth of about 130 feet below the surface, being lined with wrought-iron drawn tubing. The upper portion of the well, for a depth of about 63 feet, had a diameter of 16 feet 5 inches and was constructed in brickwork; it served as a pump well. For the complete installation, two vertical compound tandem engines and two treble-barrel pumps were proposed, one of the sets to be erected at first, and two Lancashire boilers. The yield of the well had been 880,000 gallons per day and would probably increase. The pumps delivered into a service tank, erected near the engine-house, having 44,000 gallons capacity and 58 feet in height above the ground. The tank had a spherical bottom and rested on an annular girder supported by the walls of the water-tower, which had been constructed in brickwork, the bedstones being of granite. The lower floors of the tower were intended to be occupied by offices and workshops. The engines, pumps, etc., had been made by Messrs. Hayward, Tyler & Co., and the general ironwork by the Horsley Company. Most of the mains and distributing pipes were too small or inserviceable, and had to be renewed. Their total length was about 28,250 yards. Mr. Nyström

Mr. Malcolm Paterson had made extensive experiments with soil drains in every position, such as must be found in all systems of drainage, and was satisfied that 2-gallon flushes—in practice often only 1½ gallon—would not suffice to maintain a perfect scour in drains laid at 1 in 40, or even with greater fall, where the length was great, especially when subjected to the check of Mr. Paterson

Mr. Paterson. a disconnecting trap. Such traps he regarded as to a large extent sewer-gas producers, more necessary where a drain lay below the house than where it did not. The liability to disturbance, settlement, bad construction, derangement of flush and obstruction, rendered more flushing power imperative. As to large gullies, it was found that the contraction of a gully, as of all water-ways, induced a better scour, not its expansion, as claimed in the Paper. The ventilation of the branch below the disconnecting trap was right, but was mostly neglected in ordinary provincial practice, and this increased the danger from such traps. Nothing appeared more satisfactory than the freest possible discharge to the outfall, with the soil-pipes outside and used as sewer ventilators. The air in such sewers was sweeter than in those in which the locking-off system as now used was in vogue. In flat districts, and upon long house-drains, a large number of disconnecting traps had been taken out. With such traps the isolation of disease was obviously impossible, since at every flush fæcal gases were pumped out at the surface. The undercutting of the 18-inch trench was of special interest, the only difficulty being how to secure proper ramming at the haunches of the sewer. The adoption of a circular arc cofferdam where the depth was great and struts difficult, was instructive. He asked if these radiating piles were grooved; and what was the fall of the permanent siphon across the Riachuelo. He supposed one reason for its division into three tubes was to strengthen it as a girder. The cement addition to the earthenware pipe spigots and sockets seemed to suggest the Archer form of earthenware pipe-joint which he had used largely. It was a double-socketed joint into which, the edges being closed with clay puddle, neat cement grout was run flush. He had removed and replaced as many as seven of these thus jointed in one length without a flaw, the whole being as rigid as a girder. The testing of the drains in area "B" was severe, but not more so than the normal pressure in a wet subsoil warranted, as even with the best workmanship some leakage could not be avoided in large brick or concrete sewers under such circumstances.

Dr. Preller. Dr. Du Riche Preller observed that the Paper contained no information with reference to periodical chemical tests, or bacteriological tests, of the River Plate water either before or after filtration. The results of such tests would be of interest. The chemical analysis given on p. 6 appeared to be an average one made in London probably many years ago. Although the result was fairly satisfactory, since it showed very little ammonia, no nitrous acid, and not more than 10 parts per 100,000 of solid

impurity, it could not indicate the composition of the water under varying conditions of so turbid a river as the Plate. In a Paper[1] on the Water Supply, Power, and Electric Works of Zurich, he had shown that chemical analysis *per se*, though valuable as a general criterion, afforded no conclusive test, unless it be supplemented by bacteriological control. At Zurich, where the potable water was derived from the lake and filtered through sand- and gravel-beds with a maximum head of water of only 6 feet, the conditions were particularly favourable, since the lake itself acted as a purifying reservoir; but even here it had happened, when the natural process of oxidation was impeded by the partial or entire freezing over of the lake, that the normal number of bacteria in the unfiltered water of only about 200 per cubic centimetre had increased to more than 2,000 for the same unit. The action of the filters was so efficient that in both cases the filtered water contained not more than twenty bacteria per cubic centimetre, whilst the chemical analysis showed no appreciable difference in either case, either before or after filtration. A tropical river like the Plate must necessarily carry a large amount of decomposing matter, and the bacteria voraciously feeding on this matter probably numbered millions per cubic centimetre, more especially after heavy rains. The reduction of the number of cases of typhoid fever at Buenos Ayres consequent upon the supply of filtered water pointed to the probability of the greater part of injurious bacteria being retained by the efficient action of the filter-beds, while the bacteria passing through the beds and hence contained in the filtered water were, in the main, harmless. Dr. Preller.

Mr. Lewis T. Wright observed that it was stated in the Paper that the installation of the house-drainage system had already produced an amelioration in the health of Buenos Ayres. It would be very interesting, if it were possible, to study the case of such a city, which had for three centuries been dependent for the disposal of its fæcal matters upon the ready penetrability of the subsoil of its dwellings, and then to trace the effects on the public health of the installation of an elaborate system of drainage. The remark on page 5 that the city was becoming more and more subject to epidemics of cholera and yellow fever was likely to give rise to a false impression, at least as regards the latter disease, for the plague that had followed the terrible Paraguayan War, and commonly thought to have been yellow fever, was previously unknown in Buenos Ayres and had not since visited the city. It Mr. Wright.

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 257.

Mr. Wright. might be supposed, simply regarding the statistics given in the Paper, that the statement put forward was well founded, since, concurrently with the commencement of the use of the sewers for house drainage, there has been a considerable reduction in the mortality. The death rates given in the Paper were not, however, in accordance with the official statistics. Before the recent amelioration in the health of Buenos Ayres could be regarded as due to the inauguration of the house-drainage system described in the Paper, it was necessary to study carefully the mortality figures, since deaths occurred in Buenos Ayres from other causes than those that might be attributed to bad drainage. For instance, in the year 1890 the deaths from the use of fire-arms were about 200 above the average. The most remarkable fall in the death rate occurred in the year 1891, and was almost entirely accounted for by a reduction in the deaths from "epidemic diseases," which were mainly typhoid, diphtheria and small-pox. Small-pox was independent of drainage, and any improvement under that head must be excluded from benefits that might have arisen from improved drainage.

In the following Table would be found the number of deaths from the three principal diseases, together with other statistics, all of which were taken from the "Anuario Estadístico de la Ciudad de Buenos Ayres."

Year.	Population.	Death Rate.	Number of Deaths.				Houses connected to Drains at the end of the Year.
			Epidemic Diseases.	Typhoid.	Diphtheria.	Smallpox.	
1872–1875	437,835	28·87	..	..	..	..	..
1887	437,835	27·59	..	..	..	..	..
1888	455,167	27·16	2,613	388	1,385	657	..
1889	523,452	28·15	1,966	509	905	185	..
1890	547,144	29·99	4,050	628	1,037	2,198	2,287
1891	535,060	24·32	1,477	408	623	275	4,359
1892	554,713	24·00	1,277	214	609	30	10,309
1893	580,375	22·00	1,126	214	658	14	15,002
1894	603,012	22·70	1,091	217	445	15	18,906

At the end of the year 1891 there had been 24,055 houses with water-supply from the mains, and some 30,000 houses without this supply, so that there were about 54,000 houses in the municipality for which these statistics apply. The proportion of the houses connected to the drains was still low; but it would be observed that the great fall in the death-rate was in the year 1891, when but a very few houses had been connected.

Taking the year 1891 into account, as it exhibited a remarkable reduction in the mortality, it might be claimed that the 220 fewer typhoid, and 414 diphtheria cases were due to the use of the sewers by about 6 per cent. of the houses, and in that case a much greater reduction in the mortality from causes attributable to bad drainage might have been expected from the further extension of the system to about one-third of the houses as in 1894. The improvement after 1890 in the public health of the city was, however, not confined to those districts supplied with sewers, but extended to parishes either outside the drainage system or where it had been in operation; and further that this improvement was also noted in the case of typhoid and diphtheria. Mr. Wright.

As districts not included within the active sphere of the drainage operations might be taken, Sta. Lucia, Flores and Belgrano. (Sta. Lucia was in the low-level district, and in which the system was not in active operation in the year 1892.)

Year.	Typhoid.				Diphtheria.			
	Whole City.	Santa Lucia.	Flores.	Belgrano.	Whole City.	Santa Lucia.	Flores.	Belgrano.
1888	388	45	23	8	1,385	172	36	13
1889	509	65	18	17	905	99	48	20
1890	628	71	43	32	1,037	143	54	33
1891	408	48	21	28	623	90	20	13
1892	214	22	12	8	609	543	34	5
1893	214	28	15	5	658	59	50	19
1894	217	19	19	16	445	63	33	19

The reduction in deaths from typhoid and diphtheria since 1890 was exhibited nearly in the same manner in undrained as in the partially drained city, and it therefore appeared that the reduction was not in any way due to the drainage works. Thus the health statistics did not justify the claim that the drainage works had reduced the death-rate, and the undoubted improvement in the health of Buenos Ayres since 1890 must be sought for in other directions. The health of the city up to the year 1890 was not considered satisfactory, and as yellow fever had moved further south and had firmly established itself in the southern part of Brazil, each approach of summer brought with it a yellow-fever scare, and the authorities were urged to action by public clamour. The compulsory notification of diseases and the rigorous disinfection of infected dwellings must have been of service in protecting the public health, and have been the cause of the reduction in the small-pox, and to this cause rather than to the drainage works

Mr. Wright. must the stamping out of the 1890 epidemic be due. There was also an extension in the paving, which removed a large number of foul, evil-smelling pools of stagnant water from the streets. The artificial immigration fostered by the practice of granting free passages to emigrants from Europe brought a most undesirable class of city loafers, who crowded into the slums, which were not confined to certain quarters of the city, but were found in every part. This immigration almost ceased after 1889, when the Government had exhausted its exchequer.

As regards typhoid, he had had the opportunity of observing in the hospitals that the majority of typhoid patients had been drinking subsoil water, and were mostly residents of the suburbs not reached by the mains of the city waterworks, and he was inclined to believe that the River Plate water as supplied by the waterworks was safe as regarded that disease. Belgrano, which had a separate supply of River Plate water from a different intake had a somewhat evil reputation for typhoid infection, and it was generally thought that the water was the cause and that the intake was contaminated by a small stream flowing into the River Plate near the intake. The plan of allowing a portion of the sewage to flow out of the storm outfalls into the river in front of the city, and at a short distance from the intake, was likely at some future time to lead to evil effects, as the foreshore, at the edge of which was the intake, might become infected.

The water from the mains was never bright and clear as the finest part of the suspended matter could not be removed by sand-filters. It could, however, be rendered bright and colourless by filtration through stone, porcelain, or even one thickness of filter-paper of good quality.

Hon. R. C. Parsons. The Hon. R. C. Parsons, in reply, said, although he was not in possession of the exact cost of filtering the water used in Buenos Ayres, he was of opinion that it did not nearly reach 1 cent gold per 1,000 gallons as stated to be the cost in Rosario by Mr. Bruce, who had, however, omitted to state how often it was necessary to clean the filters at Rosario. Should their construction or the turbidity of the water of the Paraná be such as to render it necessary to renew the sand more frequently than at Buenos Ayres this excessive cost might be accounted for. The advisability of roofing the filters had been very carefully considered before it was finally adopted at Buenos Ayres, and it was determined that not only would the cost of cleaning the filters be considerably reduced, owing to the process of filtration being carried on in the dark, and the formation of vegetable growths thus prevented, but

Hon. R. C. Parsons.

also, in the hot season, when the temperature was tropical, the water would be cooler and of greater purity when supplied to the city. From the description given by Mr. Bruce of the system of piping adopted in Rosario, it appeared that the principle followed was almost identical with that in use in Buenos Ayres, except that instead of two distributing mains laid under the pavements on either side of the streets, one was provided under the centre of the street. This course had been adopted in Buenos Ayres, as the streets were so narrow, and in most cases tramway rails were laid in them, the passage of the cars along which would have been seriously impeded whenever it was necessary to make a connection to the distributing main were it laid under the roadway. In a large system of street mains very serious inconvenience would be met with should it be necessary to empty and refill a main if air-valves were omitted, as the house-owners would, in that case, be a considerable time before they blew off the air and obtained the water they required. The opinion that the system of ventilating-pipes, as adopted in Buenos Ayres, was unnecessary, and that the street man-holes give all the ventilation required, had been formerly held in England, but it was now very generally admitted that the ventilation of sewers might with advantage be improved, and he considered that if this was he case in a country possessing a temperate climate, it was absolutely necessary in a country where the heat was tropical, and which was subject to visitations of cholera and yellow fever. The designs of the additional settling-pools and filters, described by Mr. Nyströmer, had been prepared by Mr. Parsons' firm, but had been modified when executed by the Government under the direction of their engineers. From careful observation of the working of the settling-pools described in the Paper he had noticed that by introducing cross-walls the current of the water, as it flowed along the channel formed by them, had the effect of stirring the deposit and preventing it from settling. He was therefore of opinion that it was preferable to construct a settling-pool rectangular in plan, allowing the water to enter along one end and to be drawn off along the other, the necessary precautions being taken to prevent local currents from being set up, which would carry the turbid water direct from the inlet to the outlet. The Argentine Government had preferred, however, to construct the new settling-pools on the same principle as those described in the Paper, which had worked successfully, and not introduce any extensive modifications in the designs.

A new form of apparatus for regulating the velocity of flow through the filtering medium, *Figs. 56*, had been described by Mr.

Hon. R. C. Parsons.

Nyströmer. The parabolic module of the apparatus described in the Paper had been replaced by a circular slide-valve worked by a cam actuated by the float which maintained a constant flow. The volume passed was also capable of being regulated by a hand-wheel at the side by rotating the casing of the valve. He considered the module described in the Paper met the requirements of the case as well as the modified apparatus, and it further possessed the great advantage that none of its working parts, which were liable to become corroded or encrusted, were below the water, as was the case in the module described by Mr. Nyströmer.

With reference to the water-supply of Belgrano, the water derived from the lower water-bearing strata, provided it remained uncontaminated by the sewage which was found in the strata above it, was no doubt suitable for domestic purposes. This subterranean water, was, however, hard, as stated in the Paper, and when the source from which the city was to be supplied had been considered it had been decided that water derived from the River Plate, when properly filtered, was most reliable and best suited to the requirements of the city.

He had carefully considered the question of the amount of water necessary for the flush, referred to by Mr. Paterson, as it was of the greatest importance in Buenos Ayres to use as little water as possible for this purpose; and it was obvious that, whilst a 2-gallon flush was sufficient to cleanse a sewer of a certain diameter, if another sewer be laid with the same gradient, but of twice the diameter, it would require a very much larger quantity of water to produce the same cleansing effect. The sewers and house-drains in Buenos Ayres had been kept as small in diameter as possible, conformably with their not being liable to become blocked, and he believed that the 2-gallon flush mentioned in the Paper was amply sufficient to keep them cleansed. In reply to Dr. Du Riche Preller, he believed that some bacteriological tests had been made, but up to the present he had not received the results.

It had been stated by Mr. Lewis T. Wright that it was asserted in the Paper that the house drainage had produced an amelioration in the health of Buenos Ayres. This, however, was not the case. A Table was given showing that the improvement in the health of Buenos Ayres had progressed as the house-drains had been connected. It was impossible to say what portion of this improvement was due to the drainage and what to the water-supply, which no doubt played a very important part, as Mr. Wright admitted. There were also other influences at work, such as a closer inspection of nuisances and the municipal regulations,

with reference to the reporting of infectious diseases, which no doubt combined to improve the general health of the city. The statistics given had been obtained from official returns, but it had been necessary to condense the Paper as much as possible, and consequently the figures given in the Tables were in a somewhat different form from those given by Mr. Wright. Hon. R. C. Parsons.

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21 January, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the chair.

The discussion upon the Paper on "The Sanitary Works of Buenos Ayres: Sewerage, Drainage, and Water-Supply," by the Hon. R. C. Parsons, was continued and concluded.

28 January, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2897.*)

"Recent Developments in Gas-Engines."

By DUGALD CLERK, Assoc. M. Inst. C.E.

IN the year 1882 the Author submitted a Paper dealing with "The Theory of the Gas-engine,"[1] in which the several inventions were classified into a few principal types. The theory of the action and efficiency of the respective types was established, and has since been fully demonstrated, while the "stratification" theory has vanished.

Great advances have been made since 1882 in the construction and efficiency of gas-engines, and the power developed by them has increased; so that the best gas-engines are now, both from the mechanical and the heat-engine standpoint, highly efficient machines. Many new engines have appeared, but all belong to one or other of the three types then classified:—1st, Non-compression engines, igniting at constant volume (explosion); 2nd, Compression engines, igniting at constant pressure (no explosion); and 3rd, Compression engines, igniting at constant volume (explosion).

For practical purposes, engines of the first two types may be disregarded; non-compression engines are now considered to be much too wasteful of gas to be of commercial importance; and compression engines of the second type have not advanced beyond the stage attained by Brayton. The expectations of the late Sir William Siemens, in which the Author shared, with regard to this type of compression gas-motor, have not been realised; and whatever may be the future of the constant-pressure hot-cylinder regenerative gas-engine, at present there is no sign of its development as a rival to the compression gas-engine of the third type.

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 220.

All gas-engines now constructed belong to the third type. They are "engines in which a mixture of gas and air is compressed or introduced under compression into a cylinder or space at the end of a cylinder, and then ignited while the volume remains constant and the pressure rises. Under this pressure the piston moves forward, and the return stroke discharges the exhaust." [1] Mechanically considered, such engines may be broadly divided into:—

A. Engines working in accordance with the Otto cycle, in which one cylinder fulfils alternately the functions of pump and motor, so that only one impulse may be obtained for two revolutions of the crank-shaft.

B. Engines having a separate pump or other charging device, by which a charge is compressed in, or introduced in a compressed state into, the power cylinder, and one impulse may be obtained for each revolution of the crank-shaft.

Engines working on the Otto cycle have proved by the test of experience to be the best adapted, of all the engines yet invented, to present needs; and their deserved popularity has gradually led to the extinction of all other types. Good results have, however, been obtained from engines giving an impulse at every revolution, most of which, both in England and on the Continent, have followed the Clerk cycle; but from various causes such engines have not kept pace with the Otto cycle engines, and so at present nearly all the engines manufactured in England are of the Otto type.

The mechanical development of the engine will be evident from the consideration of a Crossley Otto engine built thirteen years ago, and of a recent engine delivered in 1892, Figs. 1 to 9, Plate 4; but it may be instructive to deal first with the advance in efficiency from the point of view of economy in the consumption of gas.

In the great majority of Otto engines, during the first forward stroke of the piston, gas and air stream into the cylinder from the beginning to the end of the stroke, the charge mixing as it enters with whatever gases the compression space may contain; the return stroke then compresses the mixture into the compression space, and when the piston has attained its full stroke and the compression is completed, ignition takes place, and the piston moves forward under the pressure of the explosion. The next instroke is the exhausting stroke. The gases thus expand after

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 222.

explosion, doing work on the piston, and the expansion terminates when the gases have attained the volume which they occupied in the same cylinder before compression commenced.

It has been shown by the Author that an air-engine supposed to carry out this cycle of operations perfectly (*i.e.*, assuming no loss or gain of heat in any of the operations, no changes of temperature except by the addition of just the necessary heat to attain maximum temperature, and the fall of temperature being due to adiabatic expansion only while the compression line also follows the adiabatic curve) has an efficiency entirely independent of the maximum temperature of the gases. Increase of the maximum temperature raises the indicated power of the engine, but does not increase the heat efficiency, or the fraction of heat converted into work.

In the Author's previous Paper,[1] the duty or efficiency, D, is given as $D = \frac{T - T'}{T}$, where T′ is the absolute temperature of the air in the cylinder before compression, and T is the absolute temperature after adiabatic compression.[2] Where t is the absolute temperature of the gases in the cylinder before compression, and t_c is the absolute temperature after adiabatic compression—

$$E = 1 - \left(\frac{t}{t_c}\right) \quad . \quad . \quad . \quad . \quad . \quad (i)$$

or more conveniently

$$E = 1 - \left(\frac{v_c}{v}\right)^{\gamma - 1} \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

Where E is the efficiency, v is the total volume of the cylinder and compression space, and v_c is the volume of the gases in the compressed state. The formula (ii) enables the theoretical efficiency to be at once calculated, provided that the relative capacities of the compression space and the volume swept by the piston be known.

Considerable advance has been made in engines of the Otto type with regard to economy in consumption of gas since 1882; at that time, the lowest consumption of gas recorded as the result of independent tests was 22 cubic feet per I.HP. per hour, as determined with Glasgow gas by the Philosophical Society of Glasgow on an engine of 8 nominal HP. In 1881, experiments were made with a 12 nominal HP. engine at the Crystal Palace Electrical Exhibition, showing a gas consumption of 23·7 cubic

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 227.

[2] See also "The Gas Engine," by Dugald Clerk, London, Longmans, Green and Co., 1886, p. 53.

feet per I.HP. per hour; and up to the beginning of 1888, the consumption does not appear to have been appreciably altered. In May of the latter year, the Author made a careful test with a 9 HP. Otto engine, No. 8705, built by Messrs. Crossley, which consumed 23·98 cubic feet of Birmingham gas per I.HP. per hour. Corresponding consumptions of Glasgow and London gas would be 22·0 and 23·7 cubic feet per I.HP. per hour. A diagram taken from that engine is shown in *Fig. 1.*

The heat evolved per cubic foot of gas varies with the composition of the gas in different towns; so that an engine might consume more gas in one town than another, and yet be converting quite as large a fraction of heat into mechanical work. To enable this to be calculated, the Author gives, in Table I

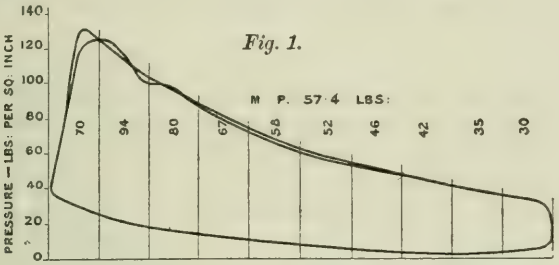

Fig. 1.

9 N.HP. CROSSLEY "OTTO" ENGINE, No. 8,705, 1888.

Diameter of cylinder, 9 inches; stroke, 18 inches; revolutions per minute, 160; 15·05 I.HP. at 58·4 lbs. mean pressure (average of three cards); gas consumption per I.HP. per hour, 23·98 cubic feet (Birmingham gas, 17 candle-power); B.HP., 13·37; gas consumption per B.HP. per hour, 27 cubic feet; maximum pressure of explosion, 133 lbs. per square inch; pressure of compression, 38 lbs. per square inch; compression space, 0·6 of volume swept by piston.

of the Appendix, analyses by Dr. Percy F. Frankland, of coal gas as supplied in nineteen of the principal towns in Great Britain, and from those particulars he has calculated Table II, which gives the various data required in gas-engine calculations. From Table II it will be found that Glasgow gas, in 1882, evolved heat equivalent to 588,530 foot-lbs. per cubic foot measured at atmospheric pressure (14·7 lbs. per square inch) and 62°·6 F. temperature. From another column it will be found that if all this heat could be converted into mechanical work it would only require 3·3643 cubic feet of the gas to indicate one HP. for an hour. The indicated efficiency, E, of an engine consuming 22 cubic feet per I.HP. hour is therefore—

$$E = \frac{3 \cdot 3643}{22} = 0 \cdot 152.$$

Calculating the London and Birmingham tests in the same manner, gives E = 0·167, and E = 0·17 respectively.

The earlier experiments of Dr. Slaby[1] and Professor Thurston[2] gave respectively 0·16 and 0·17 as the indicated efficiency of engines not greatly differing in dimensions. It may be considered, then, that up to the end of 1887, the best efficiency of Otto engines of between 5 I.HP. and 15 I.HP. was as nearly as possible 0·17; that 0·17 of the heat of the gas appeared on the diagram as indicated work. Both the experimenters referred to have erroneously calculated the heating value of the gases used by excluding the heat of evaporation of the water formed. Correcting their results for this, the efficiencies become respectively 0·14 and 0·15. The compression used up to this time did not exceed 40 lbs. per square inch above atmospheric pressure.

At the end of 1888, an important series of tests was made by the Society of Arts; Dr. John Hopkinson, Dr. Kennedy, and Mr. Beauchamp Tower acting as judges for the Society. These trials were intended to compare the relative merits of various motors for electric lighting, three gas-engines and one steam-engine being entered for trial. All the gas-engines were worked in accordance with the Otto cycle. The engine submitted by Messrs. Crossley had a cylinder 9½ inches in diameter, with a stroke of 18 inches. The consumption of gas at full load was found to be 20·55 cubic feet per I.HP. hour, and the compression was 61·6 lbs. per square inch above atmospheric pressure, and volume of compression space 0·4 of that swept by piston. The indicated HP. was 17·12, and the brake HP. 14·74 at a speed of 160·1 revolutions per minute; the gas consumed per brake HP. hour was 23·87 cubic feet, or, allowing for igniting flame, 24·10 cubic feet. The mean effective pressure was 67·9 lbs. per square inch; and the mean initial pressure of the explosion was 196·9 lbs. The heating value of the gas used was found by analyses to be 483,270 foot-lbs. per cubic foot, the gas being measured at 32° F., and 14·7 lbs. per square inch atmospheric pressure. The temperature of the gas in the meter was 64°·4 F., and the barometric pressure 14·9 lbs. per square inch, so that 4·308 cubic feet would be required to

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[1] Jenkin, "Gas and Caloric Engines," Appendix IV, Lectures Inst. C.E., Session 1883–84.

[2] "Experiments on an 'Otto' Gas Engine," Van Nostrand's *Engineering Magazine*, vol. xxx., 1884.

furnish heat-units equivalent to one HP. for an hour. The absolute efficiency was therefore—

$$E = \frac{4 \cdot 308}{20 \cdot 55} = 0 \cdot 21.$$

Thus, at the end of 1888, the best result obtained from a Crossley Otto engine was, according to the Society of Arts experiments, the conversion of 21 per cent. of the heat supplied to the engine into indicated work appearing on the diagram; a creditable advance on the consumption of the Otto engine in 1882. In the Author's opinion, however, an erroneous basis of calculation for the determination of the heating value of coal-gas was adopted. In the heating value of the gas was included only heat evolved by cooling the products to 212° F. The whole heat of combustion from the temperature before ignition down to the same temperature should be taken in any estimation of the absolute heat efficiency of an engine. Amending the Society of Arts calculation for this, 3·88 cubic feet of gas would give sufficient heat, if all were converted into work, to give one HP. for an hour, so that the absolute efficiency would be $\frac{3 \cdot 88}{20 \cdot 55} = 18 \cdot 9$ per cent. instead of 21 per cent.

From 1888, until 1894, the latter figure remained as the best Otto engine consumption; but in the latter year Messrs. Crossley, in conjunction with Mr. James Atkinson, succeeded in obtaining considerably greater economy. Messrs. Crossley Bros. placed one of their new type of 4-HP. (nominal) engines at the Author's disposal for the purposes of a test, in order to verify the extraordinarily low consumption obtained. Accordingly he made a very careful test at Openshaw on the 31st August, 1894. *Fig.* 2 is a diagram taken from that engine.

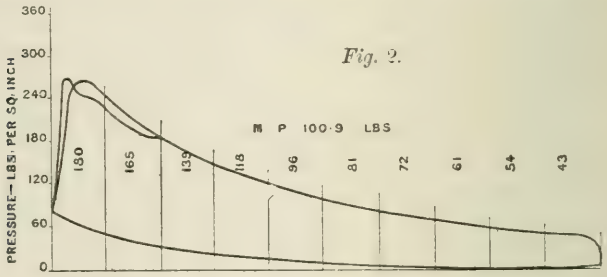
Taking the heating value of Openshaw gas as 530,000 foot-lbs. per cubic foot at 62°·6 F., and 14·7 lbs. pressure per square inch, 3,736 cubic feet would supply heat enough, if all converted into work, to perform 1 HP. for an hour. As the consumption per I.HP. hour is 14·8 cubic feet it follows that the absolute indicated efficiency is

$$E = \frac{3 \cdot 736}{14 \cdot 8} = 0 \cdot 25;$$

that is, the engine converts 25 per cent. of all the heat given to it into indicated work. This is an extraordinarily good result, and as it was much lower than any gas consumption the Author had

ever noted before, he had every necessary test made of the meter, the brake weights and the indicator, in order to make certain of substantial accuracy. This engine, although possessing only a 7-inch cylinder with a 15-inch stroke, gave practically 12 brake HP. with a gas consumption of only 17 cubic feet of gas per brake HP. hour, a surprisingly good result for so small an engine. With a larger engine better results are obtained; with an engine of 14 nominal HP., having an $11\frac{1}{2}$-inch cylinder diameter of 21-inch stroke, Mr. J. Atkinson obtained, also at Openshaw, an average available pressure of 100 lbs. per square inch, 46·8

Fig. 2.



4 N.HP. Crossley "Otto" Scavenging Engine.

Diameter of cylinder, 7 inches; stroke, 15 inches; revolutions per minute, 200; I.HP., 14 at 100 lbs. per square inch mean pressure (average of three cards); gas consumption per I.HP. per hour, 14·8 cubic feet (Openshaw gas, 20 candle-power); B.HP. 11·97; gas consumption per B.HP. per hour, 17 cubic feet; maximum pressure of explosion, 275 lbs. per square inch pressure of compression, 87·5 lbs. per square inch; compression space, 34 per cent. of volume swept by piston.

indicated HP., and a gas consumption of 13·55 cubic feet per I.HP. hour. This gives an absolute indicated efficiency of

$$E = \frac{3 \cdot 736}{13 \cdot 55} = 0 \cdot 275.$$

Substantial improvement has therefore been made by Messrs. Crossley in the economy of gas since 1882, and it is interesting to note that each step of diminished gas-consumption is attended by an increase in compression; this is evident from the Table on the following page. The experiments (1) and (2) were made with engines having cylinders 9 inches and $9\frac{1}{2}$ inches in diameter respectively, both engines having an 18-inch stroke; so that they may be considered to be of the same dimensions so far as change of economy due to change of dimensions is concerned. The result (3) was obtained with an engine having a cylinder of 7 inches diameter and 15 inches stroke, so that 0·26 would more properly

represent the efficiency to be obtained from an engine of the same dimensions as in the other experiments.

Absolute Indicated Efficiency of Crossley "Otto" Engines of similar size since 1882.

—	Efficiency.	Pressure of Compression above Atmosphere.
		Lbs. per Sq. In.
1. 1882-88 . . .	0·16	38·0
2. 1888–94 . . .	0·19	66·6
3. 1894	0·25	87·5

From these results it is evident that economy increases with compression. But it is open to question whether the increased compression completely accounts for the improved performance. If the calculated result from the various compression pressures accounts for the whole change of gas consumption accompanying change of pressure, then it is evident that the improved economy is to be credited to the increase of compression only. To test this, the Author has calculated, by formula (ii), the theoretical efficiency of an air-engine in which no practical losses occurred, the air-engine having the same ratios of compression space as the actual gas-engines. These theoretical efficiencies are shown in the appended Table placed beside the actual efficiencies obtained in the gas-engine.

From this Table it is evident that the improved economy is chiefly accounted for by the increased compression, in every case the actual indicated efficiency obtained from the various gas-engines ranges from a little under to a little over half of that which would be given by an ideal air-engine following the same cycle in a perfect manner without loss of heat to the sides of the cylinder.

The actual efficiency improves somewhat more rapidly with the increase of compression than does the thermodynamic advantage due to compression. That is, when the theoretical efficiency is 0·33, the actual experimental efficiency is $0·33 \times 0·45 = 0·15$, with theoretical efficiency 0·39 the actual efficiency is $0·39 \times 0·48 = 0·19$, while with 0·428 theoretical, the actual efficiency is $0·428 \times 0·58 = 0·25$.

The ratio of actual to ideal efficiency thus rises from 0·45 to

0·58. This means that with higher compressions in addition to the thermodynamic advantage due to change of cycle, there is also a further advantage due to a diminution of the proportional loss of heat to the cylinder walls.

TABLE SHOWING THEORETICAL INDICATED EFFICIENCY OF CROSSLEY "OTTO" ENGINES WITH DIFFERENT COMPRESSIONS, COMPARED WITH ACTUAL INDICATED EFFICIENCIES WITH THE SAME COMPRESSIONS.

E = Calculated Efficiency for perfect "Otto" Cycle Engine from Compression Space Volume.	E = Actual Indicated Efficiency from Diagram and Gas Consumption.	Ratio of Actual to Ideal Efficiency.	Cylinder Diameter.	Piston Stroke.	Ratio of Compression Space to Space swept by Piston.	Pressure of Compression.	Gas Consumption per I.HP. per Hour.
			Inches.	Inches.		Lbs.	Cub. Feet.
0·33	0·15	$\frac{0·15}{0·33} = 0·45$	9	18	0·6	38·0	24·0
0·4	0·189	$\frac{0·189}{0·40} = 0·47$	$9\frac{1}{2}$	18	0·4[2]	61·6	20·5
0·39[1]	0·19	$\frac{0·19}{0·393} = 0·48$	$8\frac{1}{2}$	18	0·418	53·0	20·3
0·428	0·25	$\frac{0·25}{0·428} = 0·58$	7	15	0·34	87·5	14·8

In the last experiment (3) part of the economy is probably due to the displacement of the exhaust products by pure air.

It follows that probably further economies are to be obtained by increase of compression, care being taken to preserve a properly shaped compression space, *i.e.*, a space having small cooling surfaces in relation to the volume of the compressed charge. Some of the advantage is also due to the more rapid conversion of the heat of the explosion into mechanical work, by reason of the small space through which the piston moves while doing a large part of the total work of its stroke.

To render the effect of compression readily visible, a diagram, *Fig. 3*, is given, in which the length of the line $a\ b$ represents the total capacity of the cylinder including the compression space; $c\ b$ represents the stroke, and $a\ c$ the compression space according to the diagram $d\ e\ f\ b$. The line $a\ g$ represents the compression space, and $g\ b$ the stroke of the "Otto" engine tested by the

[1] Test by Prof. Capper; "A Text-book on Gas- Oil- and Air-Engines," by Bryan Donkin, M. Inst. C.E., Appendix, Section A, p. 355.

[2] This value is given by the Society of Arts, but it appears wrong.

Society of Arts, while *h i k b* is the diagram given in the Society of Arts Report plotted to the same scale as the first diagram. The line *a l* represents the compression space, and *l b* the stroke of the engine tested by the Author at Messrs. Crossley's works, while *m n o b* is the diagram 3. It is evident that No. 2 is larger in area than No. 1, and that No. 3 is considerably larger than both. The diagrams, Nos. 1 and 2, were taken with precisely the same amount of gas present in the cylinder per cubic foot of space; but in the case of No. 3 the amount of gas present was greater, so that to truly represent the respective economies obtained by the three compressions, the diagram No. 3 should be diminished.

The increased heat-efficiency of the Crossley "Otto" cycle engine is then clearly in the main due to increased compression;

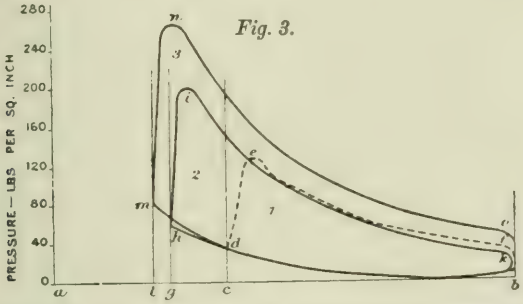


Fig. 3.

Diagram showing Effect of Increased Compression.

it is now advisable to consider the mechanical changes which have accompanied and rendered possible these economies.

Comparison of a Crossley Otto Gas-Engine built in 1882, and one built in 1892.—Figs. 4 to 6, Plate 4, show details of a Crossley Otto engine, No. 4683, of 6 HP. nominal, built about 1882 and now at work in Birmingham. Figs. 7 to 9, Plate 4, illustrate a recent engine, No. 19,772, of 9 HP. nominal, by the same makers, now at work at the Clifton Rocks Railway, Bristol. Figs. 5 show the valve and lever arrangements; and a section showing the position of the slide-valve port and funnel is given in Figs. 6.

A comparison of the illustrations shows at once that the later engine is a great improvement upon the earlier in design. From a constructive point of view the earlier type had several inconvenient features which have been removed; thus, the cylinder in the earlier type of engine had to be adjusted accurately con-

centric with the guide forming part of the engine frame; this difficulty has been overcome by making the cylinder serve both as cylinder and slide-guide; the whole being bolted to the bed against a strong faced flange, and this permitting of the ready removal of the liner when required. The bevil-wheels are replaced by skew-wheels, and this provides a much quieter drive for the two-to-one cam-shaft, while avoiding the somewhat unsightly distortion of the bed of the earlier engine in order to get the bevil-wheels properly applied.

There are many small constructive details which experience has shown to be desirable; but the great points of departure between the two engines, which result in the superior economy of the later one, are to be found in (*a*) the abandonment of the flame slide-valve method of ignition, and the substitution for it of ignition by an incandescent metal or other tube; (*b*) the diminution in the relative volume of the compression space; and (*c*) the improved proportioning of the valves and ports in order to minimise the throttling of the charges during the inlet period, and the back pressure of the exhaust gases during discharge.

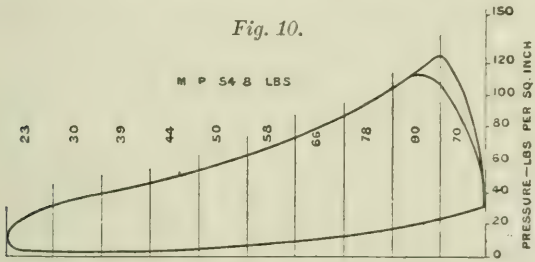
In the slide-valve Otto engine, Figs. 4 to 6, the port in the back cover is $2\frac{3}{8}$ inches by $\frac{5}{8}$ inch, or $1\frac{1}{2}$ square inch in area, and a maximum pressure of 150 lbs. per square inch is often attained in this engine. This means that the slide-valve has to be held to its cover by a pressure exceeding 225 lbs.—as a matter of fact, the pressure of the springs on this slide exceeds 600 lbs. When it is considered that the flame temperature of the contents of the cylinder and port is about 2,912° F., it is easy to see how great is the difficulty of keeping the slide in working order, even at the lower compressions.

The slide-valve in these engines undoubtedly presented a formidable difficulty, and so long as it remained essential, prevented the successful use of higher compression and flame pressures. Messrs. Crossley appear to have abandoned the slide-valve for the first time in the engine built for the Society of Arts trials, and they then applied the incandescent-tube igniter. The igniter used by them until recently is shown in section at Figs. 8, 9, Plate 4. This form of igniter appears to have been proposed for the first time by the late Sir C. W. Siemens, but it was not successfully applied until re-introduced by Mr. J. Atkinson about 1880. In Great Britain the tube igniter has now displaced all other forms of igniting gear. It allows the compression to be increased to any desired extent, without giving rise to practical difficulties. The higher compression which is made practicable

by this igniter is the main distinguishing feature between the early and the recent Crossley Otto engines illustrated.

Another important difference also follows from the abandonment of the slide-valve. In the older engines the limitation of the admission area through the slide was important, and so the entering air and gas charge was somewhat throttled. A test was made of the slide-valve engine, Figs. 4 to 6, by the Author in September, 1894, from which he obtained the diagram, *Fig. 10*. With this engine, assuming the port to be fully open during the whole forward stroke, and taking the average piston-speed as 437 feet per minute, there is given with a cylinder area of 50·26 square inches, an average velocity of the air and gas mixture flowing through the port of 244 feet per second. Hence considerable throttling is caused, so that when the piston attains its complete out stroke, the pressure in the cylinder is below that of

Fig. 10.



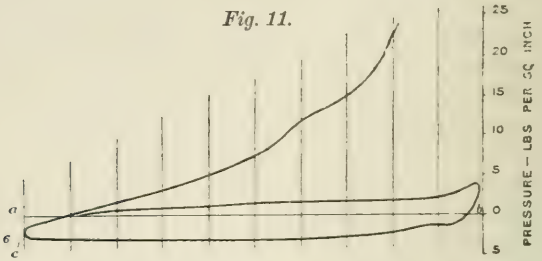
6 N.HP. Crossley "Otto" Slide-Valve Engine, 1881.

Diameter of cylinder, 8 inches; stroke, 16 inches; revolutions per minute, 164; I.HP. at 57 lbs. mean pressure (average of four cards), 9; gas consumption per I.HP. per hour, 25·5 cubic feet Birmingham gas); B.HP., 6·75; consumption per B.HP. per hour, 34 cubic feet; maximum pressure of explosion, 126 lbs. per square inch; pressure of compression, 31 lbs. per square inch; compression space, 0·64 of the volume swept by the piston.

the atmosphere. To allow the cylinder to fill as much as possible, the admission port in the slide was set to remain open until the crank had crossed the out centre and the piston had just begun its instroke. Notwithstanding this, the pressure in the cylinder at the outer end of the stroke was somewhat below that of the atmosphere. This is clearly shown in *Fig. 11*, which is a diagram taken with a light spring, to show the charging stroke. It will be seen that at the outer end (6) of the charging stroke, the point *c* is considerably below the atmospheric line *a b*, and that the pressure within the cylinder is only 13·0 lbs., instead of 14·7 lbs. per square inch. This seriously reduces the charge taken into the cylinder, and so makes the mean available pressure much less. The available area of the exhaust opening is only 2·65 square

inches, so that the average velocity of the exhaust gases is 137·3 feet per second, which is quite reasonable for hot gases; but it is such a velocity as to cause undue resistance to the dis-

Fig. 11.

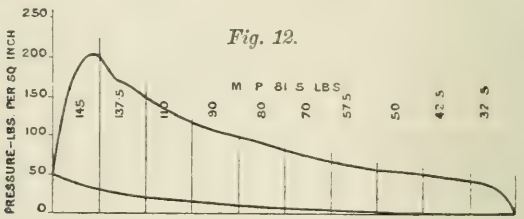


Light-Spring Diagram, 6 N.HP. Crossley "Otto" Slide-Valve Engine, 1881.

charge of cold gases, and as cold air is discharged while the engine is governing it is desirable to reduce it.

Fig. 12 is a diagram taken by the Author in a recent test of the Otto engine illustrated in Figs. 7 to 9, Plate. 4. In this engine the piston speed was 480 feet per minute, and the area of the cylinder was 70·88 square inches. The suction area of the inlet gas- and air-valve when fully open was 4·43 square inches; and the velocity of the entering charge was 128 feet per second, assuming the valve fully open during the

Fig. 12.



9 N.HP. Crossley "Otto" Engine, 1892.

Diameter of cylinder, 9½ inches; stroke, 18 inches; revolutions per minute, 160; I.HP., 19·25 at 81·5 lbs. mean pressure (average of four cards); gas consumption per I.HP. per hour, 21·19 cubic feet (Clifton gas); B.HP., 15·75; consumption per B.HP. per hour, 25·9 cubic feet; maximum pressure of explosion, 200 lbs. per square inch; pressure of compression, 48 lbs. per square inch; compression space, 0·4 of piston displacement.

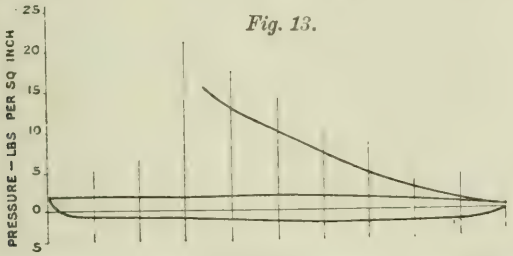
whole stroke. The maximum area of exhaust discharge was 7·06 square inches, so that the speed of exhaust discharge was 81 feet per second, assuming the valve to be full open during the whole exhaust stroke. The light-spring diagram, *Fig. 13*, shows

the great improvement effected by so diminishing the resistance to the inlet and the discharge.

It is to be remembered that the evil effect of throttling the admission of the gas and air charge is not confined to the power absorbed by the extra resistance, which is trifling. In this engine, for example, a reduction of 1½ lb. per square inch below atmospheric pressure at the out end of the stroke means that the total volume of charge admitted is reduced by about 20 per cent., because the reduction of pressure affects not only the volume swept by the piston, but also the volume of the clearance space. The leading data of these two "Otto" engines are arranged in Table III of the Appendix in such a form as to enable comparison to be readily made.

The Crossley "Otto" engines now built differ considerably from the engine No. 19,772, constructed in 1892; they are now of the "scavenging" type, and are similar to that tested by the Author at their works, *Fig. 2*. This engine operated somewhat

Fig. 13.



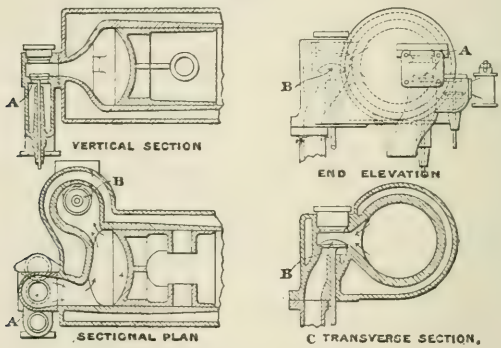
Light-Spring Diagram, 9 N.HP. Crossley "Otto," 1892.

differently from that shown in Figs. 7 to 9. The general design, bed and details were the same, but an important improvement was made, which possessed an additional advantage in introducing no complications.

The Author has long contended that no advantage has ever been gained in the "Otto" or any other gas-engine, by retaining the products of combustion in the compression space. These products are better discharged and the space filled with combustible mixture or pure air, if it can be effected without mechanical complications. Many of the Author's experiments were conducted specially with that end in view, as applied to engines with an impulse at every revolution. From being among the most prominent holders of what may be called the "combustion products" theory of the cause of economy in gas-engines, Messrs. Crossley have entirely adopted the Author's view of the causes of economy

in the modern gas-engine; and their new invention offers proof that considerable advantages are to be obtained by clearing out the whole of the burned gases. It has been long known that if a puff of steam or gas be discharged into a long pipe, after a certain time the wave of pressure is succeeded by a fall of pressure, or partial vacuum. Messrs. Crossley and Atkinson take advantage of this, and control the wave and the following vacuum in such a manner that, after the exhaust gases have been liberated from the cylinder, the high-pressure discharge is succeeded by a vacuum; and they so proportion the length of the exhaust pipe that the vacuum period in the pipe coincides with the piston nearing the end of its stroke. By keeping open the exhaust-valve, and opening the charge or air inlet-valve while the exhaust-valve is open, a charge of pure air, or air and gas if

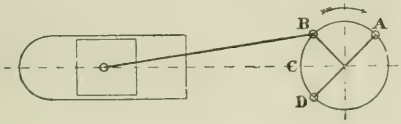
Figs. 14.



need be, is drawn through the combustion space of the engine; and all the products of combustion which would otherwise remain there are swept out from the compression space. When the charging stroke is complete, the cylinder is thus filled with a pure mixture of air and gas without the deleterious burned gases. To accomplish this sweeping-out in a satisfactory manner, it is necessary to shape the cylinder so as to favour a clean sweep by the entering air. *Figs. 14* illustrate the arrangement of the 4-HP. nominal engine tested by the Author. *Fig. 15* illustrates diagramatically the settings of the valves in that engine. The desired delay in the production of suction or vacuum is caused by attaching an exhaust pipe (C) about 65 feet long to the exhaust passage. Quieting chambers may be placed at that length of the pipe without ill effect; but the pipe must be arranged without

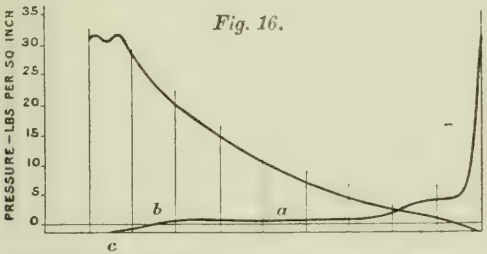
any large expansion or chamber for about that length. It may be bent as much as is necessary to get in the requisite length. The energy of discharge of the exhaust sets the long column filling

Fig. 15.



this pipe in motion, and produces a considerable reduction of pressure within the cylinder, notwithstanding the opening of the air-valve.

Fig. 16.

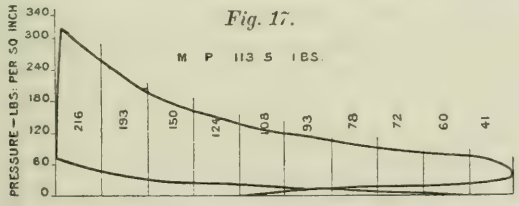


LIGHT-SPRING DIAGRAM, 4 N.HP. CROSSLEY "OTTO" SCAVENGING ENGINE; AUGUST 31, 1894.

Showing how the exhaust-line *a* strikes the atmospheric-line at *b* and falls below it to *c*, so causing suction through the cylinder to displace the exhaust.

The light-spring diagram taken from the engine during the Author's test, *Fig. 16*, shows plainly the effect of the vacuum so produced in the exhaust pipe. The pressure is reduced within the

Fig. 17.



30 N.HP. CROSSLEY "OTTO" SCAVENGING ENGINE. DIAGRAM FROM ENGINE WITH COAL-GAS.

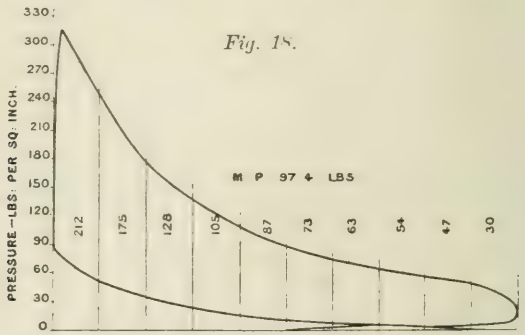
Cylinder, 17 inches diameter; stroke, 24 inches; pressure of compression, 75 lbs. per square inch; maximum pressure of explosion, 318 lbs.; I.HP., 121, with an average pressure of 113·5 lbs. per square inch.

cylinder to 2 lbs. below atmosphere, quite enough to cause a strong current of air to sweep through the cylinder. In *Figs. 11* the arrows show the air sweeping in by the inlet-valve A through

the specially shaped cylinder, and out at the exhaust-valve. The air inlet-valve is opened while the crank is in position D, *Fig. 15*, and the exhaust-valve is held open until the crank reaches the position B. The exhaust-valve opens again at A, and it is held open to B instead of as usual to C. The method has been applied by Messrs. Crossley to engines of more than 100 I.HP.; *Fig. 17* is a diagram taken from a 30-HP. nominal engine, giving with coal-gas 121 I.HP., on an average available pressure of 113·5 lbs. per square inch. The compression shown is 75 lbs. per square inch.

A diagram taken from the same engine, with Dowson gas, is shown in *Fig. 18*, from which it will be observed that the very satisfactory average pressure of 97·4 lbs. per square inch was attained.

Fig. 18.



30 N.HP. Crossley "Otto" Scavenging Engine with Dowson Gas.

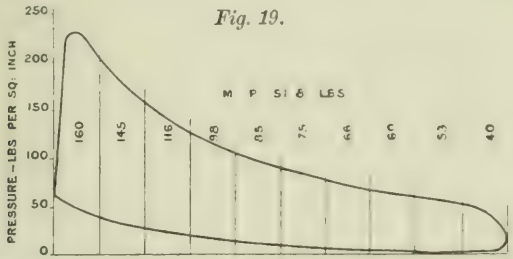
Cylinder, 17 inches diameter; stroke, 24 inches; card from same engine as in Fig. 17.

Mr. J. Atkinson, in a Paper[1] read before the Manchester Association of Engineers, attributes the whole of the economy he has obtained to the discharge of the exhaust gases and their replacement by pure air, and he entirely omits to note the effect of the increased compression which is used in conjunction with the scavenging air. The Author has always advocated "scavenging" a cylinder by means of air, and in many engines designed by him has entirely discharged the exhaust gases by air forced in by a pump. He has never been able, however, to credit such scavenging with more than 5 per cent. of economy, as compared with the same engine working at the same compression and retaining the exhaust gases. The results of many tests with gas-engines of the "three cycle" variety of Otto type, in which one revolution is

[1] *Engineering*, vol. lviii. p. 719.

devoted to replacing the whole of the exhaust gases by air, proves distinctly that the gas consumption per I.HP. at low compressions is not materially reduced by the act of displacing the exhaust products. Such engines have been constructed by Linford, Griffin, Barker and others before the expiry of the Otto master patent, but they did not show a large economy due to pure charge. The Author is indebted to Mr. A. R. Bellamy of Reddish, for the diagrams, *Figs. 19* and *21*, taken by him from a Stockport Otto cycle gas-engine having a cylinder of $9\frac{3}{4}$ inches diameter by 17 inches stroke.

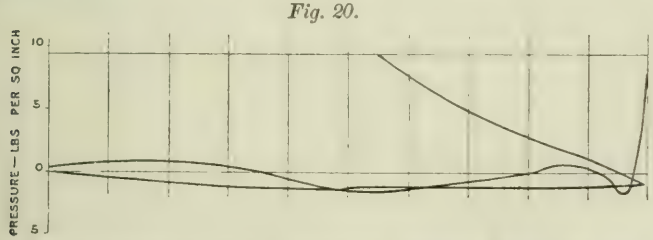
Fig. 19.



9 N.HP. Stockport "Otto" Engine, 60 Lbs. per Square Inch Compression; Engine No. 6,242.

Diameter of cylinder, $9\frac{3}{4}$ inches; stroke, 17 inches; revolutions per minute, 184; B.HP. 20·8; consumption per B.HP. per hour, 22·3 cubic feet; maximum pressure of explosion, 244 lbs per square inch.

Fig. 20.



Light-Spring Diagram, 9 N.HP. Stockport "Otto" Engine, 60 Lbs. per Square Inch Compression; Engine No. 6,242.

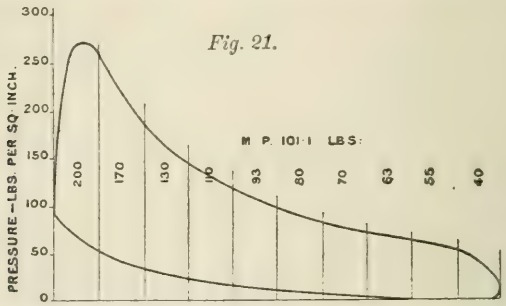
The only difference between the two experiments is that in the first the compression space of the engine is proportioned to give a compression pressure of 60 lbs. per square inch, while in the second one the compression is 90 lbs. per square inch above the pressure of the atmosphere. The engine, when working with 60 lbs. per square inch compression, consumed 19 cubic feet per I.HP. hour; while with 90 lbs. per square inch compression the consumption was reduced to 17·6 cubic feet per I.HP. hour. The heat value of Reddish gas is about 500,000 foot-lbs. per cubic foot.

and so the efficiencies stand, with 60 lbs. per square inch compression, 0·208; with 90 lbs. per square inch compression, 0·225.

Figs. 20 and *22* are light-spring diagrams from the engines taken with the cards *Figs. 19* and *21* respectively. The light-spring cards are practically the same, and show that no scavenging took place in the cylinder during either of the tests. It is therefore proved that in this experiment the improvement in economy is due to increase of compression only.

Scavenging by pure air, however, although not the sole cause of

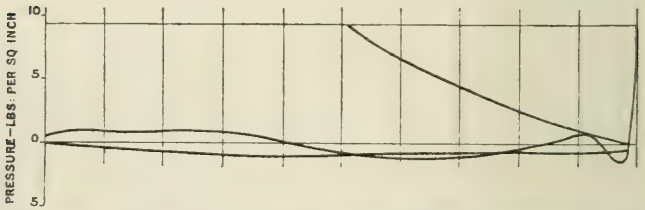
Fig. 21.



9 N.HP. Stockport "Otto" Engine, 90 Lbs. per Square Inch Compression; Engine No. 6,242.

Diameter of cylinder, 9¾ inches; stroke, 17 inches; revolutions per minute, 182; B.HP., 24·4; consumption per B.HP. per hour, 20·75 cubic feet; maximum pressure of explosion, 272 lbs. per square inch.

Fig. 22.



Light-Spring Diagram, 9 N.HP. Stockport "Otto" Engine, 90 Lbs. per Square Inch Compression; Engine No. 6,242.

economy in the new engine, has great practical advantages, and, in the Author's opinion, it is absolutely essential to success with large gas-engines, especially when high compression is adopted. A great difficulty with large engines, and those using high compression, arises from liability to the premature explosion of the mixture during the act of compression. This is largely caused by the presence of hot exhaust gases; and when these hot gases are

removed by pure air, the cold pure mixture may be compressed to very high pressures without danger of early ignition. The admission of air in the first place also prevents any chance of the incoming charge being ignited during the charging stroke. The new method introduced by Messrs. Crossley & Atkinson is therefore most valuable, permitting of working under conditions of maximum economy, and its very simplicity increases its value by avoiding the use of pumps or other mechanical air-supplying devices. It would occupy too much space to discuss the many ingenious details of the Crossley Otto engines of different sizes; the large engines of 250 I.HP. are, however, specially interesting.

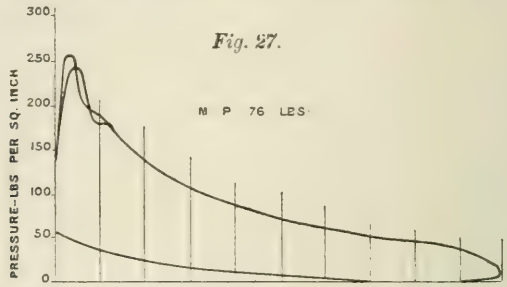
Many economical and well-designed engines of the Otto cycle are now built by various firms of manufacturers, exhibiting only small variations in mechanical detail. The engines made by Messrs. Andrew & Co. of Reddish are well designed, and as may be seen from *Figs. 19* and *21*, high economy is attained. Messrs. Andrew have built very large engines for mill purposes, using Dowson gas, and in Figs. 23, Plate 5, is shown an engine of 400 I.HP. built by them and erected at Messrs. Spicer's works at Godalming. This is at present one of the largest gas-engines in the world. Its arrangement is novel and interesting. Two cylinders are mounted in tandem on a bed-plate. To avoid passing a piston-rod through a combustion-space, the pistons are connected by piston-rods, crossheads, and side rods; both connect thus to a single crank-shaft by a common connecting rod. Each cylinder works on the Otto cycle, but the valves are timed to make the explosions alternately. In this manner an impulse is obtained for every revolution of the fly-wheel. Fig. 24, Plate 5, illustrates the arrangement of one of Messrs. Andrew's engines of moderate dimensions, and Fig. 25 is a section of their combined timing- and starting-valve. This engine resembles, as do most gas-engines, the Crossley engine, in having separate inlet and exhaust passages leading from the combustion space.

In the Author's opinion, engineers have not sufficiently recognised the importance of limiting port surface to the utmost. By so doing, the cooling surface in contact with the intensely hot gases in minimised. By reducing or abolishing passages leading into the combustion space, less heat is lost during the explosion period. Messrs. T. B. Barker & Co. have kept this point well in mind while designing the Otto cycle engine illustrated at Fig. 26. The valves are placed in the cylinder in such manner that passage or port surface is avoided. The inlet-valve is within the cylinder, and the exhaust-valve is placed close beside it. The engine

illustrated is of 12 HP. nominal, and the diagrams, *Figs. 27* and *28*, show high economy.

An engine of Messrs. Barker's construction, tested by Mr. J. M. Morrison, at the Saltley gasworks of the Birmingham Corporation at the beginning of 1894, gave the highest economical results, Fig. 29, attained within the Author's knowledge by any engine previous to the Crossley Scavenging engine. From this it appears that the engine consumed, on an average of four tests,

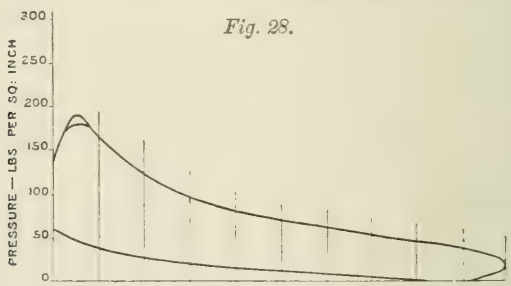
Fig. 27.



12 N.HP. BARKER "OTTO" ENGINE, FULL LOAD.

Diameter of cylinder, 10 inches; stroke, 18 inches; revolutions per minute, 180; I.HP., 24·4 at 76 lbs. per square inch mean pressure; gas consumption per I.HP. per hour, 18 cubic feet; gas consumption per B.HP. per hour, 21·5 cubic feet; maximum pressure of explosion, 244 lbs. per square inch; pressure of compression, 55 lbs. per square inch.

Fig. 28.



12 N.HP. BARKER "OTTO" ENGINE, NO LOAD.

Running light diagram at 194 revolutions per minute.

only 21·3 cubic feet of gas per brake HP. per hour, or 17·2 cubic feet per I.HP. hour, which is an extraordinarily low consumption for an engine using Birmingham gas. The compression was only 50 lbs. per square inch, so that much of the high efficiency undoubtedly arises from the great diminution of port surface within the cylinder.

Self-Starting Gear.—Before leaving the Otto cycle engines, it may be advisable to describe briefly the starting gears which are

now used for such engines. The great increase in the power of the engines manufactured has made it imperative to dispense with the old manual method of starting gas-engines.

The first starting gear introduced in Great Britain was invented by the Author, and it was applied to the Clerk impulse-

Fig. 29.

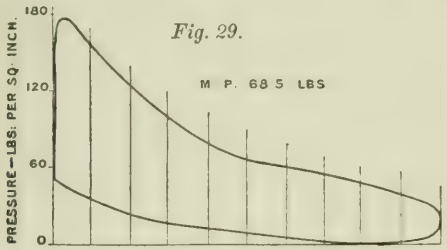
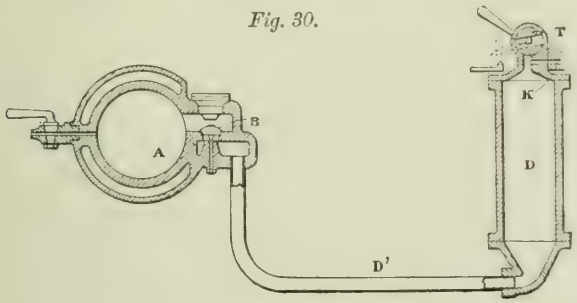


DIAGRAM FROM BARKER "OTTO" ENGINE, SALTLEY GASWORKS.

Diameter of cylinder, 12 inches; stroke, 20 inches; revolutions per minute, 156; I.HP., 24·3 at 67 lbs. mean pressure (average of a number of cards); Saltley gas; consumption per I.HP. per hour, 17·2 cubic feet; B.HP., 19·9; consumption per B.HP. per hour, 21·3 cubic feet; maximum pressure of explosion, 195 lbs. per square inch; pressure of compression, 50 lbs. per square inch.

every-revolution engine in 1883; it is fully described in his book.[1] That starter required to store up air or a mixture of gas and air under compression, which was found to involve expensive arrangements; and although the gear was quite satisfactory in action, the first cost was too high. The starting

Fig. 30.



CLERK PRESSURE STARTER.

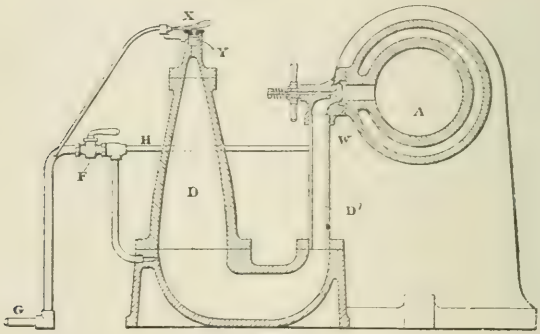
gear now used more extensively than any other is also an invention of the Author; and the Clerk starter is now applied by Messrs. Crossley, who have acquired the patent, to all engines which require a starter. *Fig. 30* is a diagramatic section illus-

[1] "The Gas Engine," London, Longmans, Green & Co., 1886, p. 239.

trating its action. A is the gas-engine cylinder, B a check-valve opening into the exhaust-port, D a chamber connected by pipe D′ with the valve B, and T is an igniting-valve. K is a port leading to a charging-pump.

The object of the device is to fill the combustion space of the engine with a compressed mixture of gas and air, and then to explode the compressed mixture, thus starting the engine by means of a high-pressure explosion. To start, the crank is placed off the centre; the pump is operated by hand to fill the chamber D, pipe D′ and cylinder A, with gas and air mixture at atmospheric pressure, so that no resistance is experienced in operating the pump. The igniter T is then operated, and the mixture in the chamber D ignites near T; the flame, as it spreads through the

Fig. 31.



Clerk-Lanchester Starter.

chamber, forces the unburned mixture before it into the pipe D′, through the valve B into the cylinder A; so that when the flame arrives at the valve B, it has swept before it into the cylinder all the unburned mixture. When the flame passes the valve B it ignites the compressed mixture in the cylinder; and, producing a high-pressure explosion, the engine is started off with an ample margin of power to overcome the friction of belting and shafting.

In conjunction with Mr. F. W. Lanchester, the Author introduced the starting gear illustrated at *Fig. 31*, which is known as the Clerk-Lanchester starter. In this arrangement a Lanchester igniting-valve Y is used, and the pump for charging the chamber D is dispensed with. When the engine is stopping, the valve W is opened and air is thus pulled through the chamber D by way of the valve Y at every suction stroke. The chamber D, pipe D′ and cylinder A thus became filled with pure air at atmospheric pressure.

When the engine is to be started, the gas-cock F is opened, and gas flows from the main at G into the chamber D, and at H into

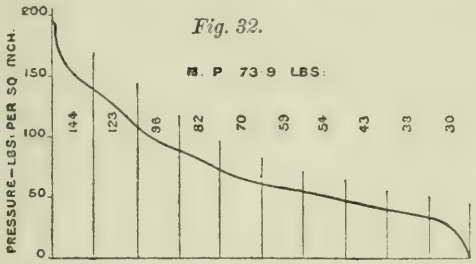
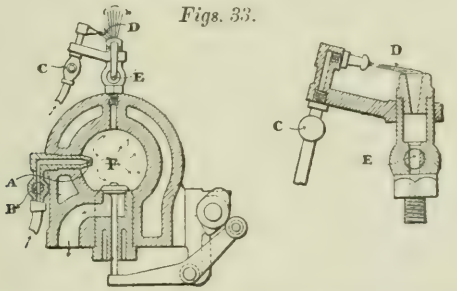


Fig. 32.

CLERK STARTER DIAGRAM.

the pipe D', a cock on the cylinder is opened to allow flow into the cylinder or the exhaust-valve is held slightly open; the flame



Figs. 33.

DETAILS OF LANCHESTER LOW-PRESSURE STARTER.

Nozzle, A; cock, B; cock, C; master-flame, D; cock, E; cylinder, F.

The gas is allowed to flow into the air-filled explosion-space in the cylinder F and flows out mixed with air through the cock E, where it is ignited by the master-flame D. When the flame assumes a certain colour, indicating the richness of mixture in the cylinder, the gas-cock B is closed and the flame rushes back into the cylinder, thus giving an impulse.

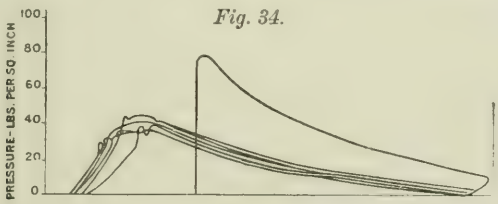


Fig. 34.

LANCHESTER STARTER DIAGRAMS.

X burns across the valve Y, and after a few seconds the mixture of gas and air escapes through Y and burns in the air. The cock F is then closed, and the flame shoots back past the valve Y, and so

ignites the mixture within D, thus closing the valve Y. The flame then proceeds along D, D' into the cylinder A, firing the mixture it has compressed, and the engine is thus started by a compression explosion. *Fig. 32* is a starting diagram obtained from this arrangement. From this it will be observed that a maximum pressure of over 200 lbs. per square inch, and a mean pressure of 74 lbs. per square inch is easily attained for a starting explosion. *Fig. 33* is a cross-section of the Lanchester low-pressure starter which is also largely used, and *Fig. 34* shows the starting diagrams.

The Clerk and the Lanchester starters may be taken as typical of the modern starters, but every manufacturer now provides a starter of some kind. Messrs. Barker and Messrs. Robey & Co. use the Lanchester starter. Messrs. Andrews also adopt a similar low-pressure starter. Messrs. Tangye start by pumping a compressed charge into the engine cylinder by a hand-pump, and then firing; while Messrs. Fielding and Platt admit compressed air from a reservoir to gas filling the cylinder, and then ignite.

Impulse-Every-Revolution Engines.—The late Prof. Faraday has well said that more is to be learned from the failure of an experiment than from its success; a statement which is as true in engineering as in physics. Smooth success is not conducive to rigorous investigation. So long as a machine performs its work easily and satisfactorily, there is little inclination to investigate in it the precise balance of cause and effect. Accordingly it is natural to find that the explanations of gas-engine phenomena come mostly from those engaged on cycles other than the Otto. From a mechanical point of view the Otto cycle is a very imperfect one, involving as its does at most an impulse for every two revolutions of the crank-shaft for each single-acting power cylinder. The mechanical imperfections of the engine up till now, however, have been more than compensated for by the simplicity due to the single cylinder and piston, and the readiness with which the practical conditions of charging, exploding, expanding, and exhausting can be made to comply with the requirements of economical working.

At first it seems to many engineers a simple matter to design a compression gas-engine capable of giving an impulse at every revolution for each single-acting motor cylinder. The problem is in reality one of the most difficult in the whole range of engineering, and, although it has been the subject of much continuous effort, no solution has yet been found which satisfies simultaneously the commercial conditions of the problem for large and for small

engines. There is now no difficulty in building impulse-every-revolution gas-engines which will give the highest possible economy, and work perfectly; but such engines, so far, cost more for small powers than Otto cycle engines of like power. For powers up to about 20 HP., it appears probable that the Otto engines will continue to monopolize the field; but the demand for larger engines is increasing so rapidly, that, in the Author's opinion, the impulse-every-revolution engine will now come into use again, and in time displace the Otto cycle for large powers.

It has always been observed that before a satisfactory solution of any important engineering problem is attained, many proposals or attempts are made by acute inventors; and, although some of them attain partial success, yet, as a rule, years elapse, one inventor succeeding another, and carrying the subject a little further, before sufficient knowledge is accumulated to make the matter commercially successful. The gas-engine has a history of this kind which the following Table will clearly indicate.

Year.	Inventor.	Nature of Engine.
1794 . . .	Robert Street . . .	Explosion without compression.
1823, 1826 .	Samuel Brown . . .	Vacuum gas-engine.
1833 . . .	W. L. Wright . . .	Explosion without compression.
1838 . . .	William Barnett . .	Explosion with compression.
1855 . . .	A. V. Newton . . .	Explosion without compression. Tube igniter.
1857 . . .	Barsanti and Matteucci	Atmospheric engine.
1860 . . .	Lenoir	Explosion, non-compression.
1862 . . .	Beau de Rochas . . .	Compression-engine, Otto cycle.
1866 . . .	Otto and Langen . .	Atmospheric.
1876 . . .	Otto	Modern Otto engine.

The Table only gives the names of a few of the leading inventors; many other propositions occur among English patents.

Street had the germ of the non-compression engine in 1794; Wright in 1833 gave it more perfect expression; but it was never successfully reduced to practice till Lenoir's engine in 1860. In 1862 a French engineer actually proposed the Otto cycle gas-engine and discussed carefully the conditions of its success; but left it to be independently discovered and reduced to practice by Otto in 1876. Otto began his long struggle with gas-engine difficulties in 1854, and achieved a partial success in 1867 with the Otto and Langen atmospheric engine, which itself was first proposed by Barsanti and Matteucci in 1857. He worked and studied until, in 1876, he invented the famous Otto engine which has proved the

turning-point in gas-motors. He had thus laboured hard at his subject for twenty-two years before real success crowned his efforts.

It has often occurred to the Author how much more rapidly engineering science would advance if inventors placed on record some description of their experimental failures as well as accounts of their successes; as one inventor succeeds another, each one goes over again, to a great extent, the ground traversed by his predecessor, and discovers for himself the difficulties which overcame him. As one who has devoted many years of persistent effort to the development of the impulse-every-revolution engine, a short account will first be given by the Author of the different engines built by him, with a statement of the difficulties peculiar to each.

The first engine built by the Author is shown in Fig. 35, Plate 5. It was designed by him early in 1878. There were two cylinders, each of 6 inches diameter by 8 inches stroke; one being a pump cylinder, the other a motor cylinder. The pump crank followed the motor crank at right-angles, and it pumped a mixture of gas and air into an intermediate reservoir through a check-valve. From this reservoir the mixture was supplied to the motor cylinder by means of a slide-valve. The mixture was compressed in the reservoir to a pressure of 70 lbs. per square inch above that of the atmosphere. The motor piston moved back to the end of the cylinder, leaving only a mechanical clearance of about $\frac{3}{4}$ inch, and the exhaust-valve was shut a little early in order to cushion the piston as is done in the steam-engine. The motor piston moved forward from the end of its stroke about 2 inches, taking in the compressed mixture from the reservoir; the slide-valve then cut off the supply, and ignition was effected by an incandescent platinum cage carried in the slide. This engine was exhibited at the Royal Agricultural Society show at Kilburn in 1879, and was, the Author believes, the first explosion compression gas-engine ever built which gave an impulse for each revolution of the crank-shaft. The Author's object in the design was to utilize high compressions, and to obtain one impulse for every forward stroke of the motor piston. The engine at full power developed 4 B.HP.

Two great difficulties were encountered after the minor difficulties, requiring the invention of special igniting, governing and starting gear, were overcome; (1) back ignition into the compression reservoir; (2) shock in the motor cylinder. The difficulty of ignition spreading from the motor cylinder to the compression reservoir was serious, and was not completely over-

come. The reservoir and the valves were made amply strong to stand the maximum pressure possible on explosion of the compressed contents; but as the reservoir contained about twelve charges from the pump, it was found that with full load on the engine it pulled up upon back ignition before the burned gases were cleared out of the reservoir. Back ignition occurred very seldom; but when it did it involved the stoppage of the engine. Various modifications were made to overcome this difficulty and that arising from shock, and the latter difficulty was obviated. The shock was due to the too rapid ignition of the contents of motor cylinder, and was avoided by changing the shape of the compression space. This engine was capable of running at high speed, the igniter being very powerful. The incandescent platinum cage was so arranged that when once heated the platinum received heat enough from the consecutive explosions to maintain it in an incandescent state. As many as 300 revolutions per minute have been attained with this engine with perfectly consecutive ignitions.

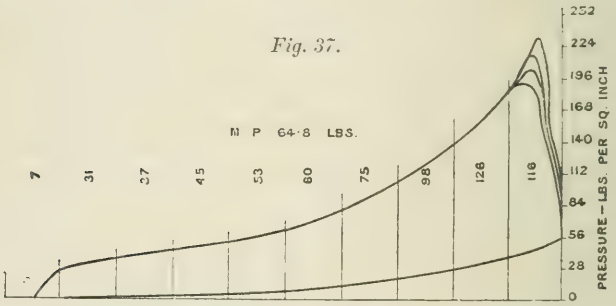
The next engine built by the Author is shown in plan and side elevation at Fig. 36, Plate 5. In it the pump does not compress its contents to the pressure of compression, but simply forces the mixed gas and air into the cylinder while the motor piston is crossing the exhaust ports at the end of its stroke; the motor piston on its return stroke compresses the charge of gas and air into a clearance space at the end of the cylinder, when the compressed mixture is ignited, propelling the motor piston forward at every revolution of the crank-shaft. The first engine of this type was designed by the Author in 1880, and was built at the end of that year. The first engine exhibited was shown at the Paris Exhibition of 1881. Several hundreds of these engines were built by Messrs. L. Sterne and Company at Glasgow, under the Author's supervision, in sizes ranging from 3 to 30 I.HP. This Clerk engine has been extensively followed in Great Britain and on the Continent, and several thousands of engines of this type have been put to work.

The results were specially satisfactory with the larger sizes, and *Fig. 37* is a diagram, with the particulars of the test marked under it, taken at Glasgow in 1885. The economy in gas at that time for the larger sizes was quite equal to that obtained with the best Otto engines. The smaller sizes, however, were less satisfactory. With engines of 20 HP. excellent results can be obtained, but with an engine developing only 4 HP. the consumption of gas was somewhat high.

The great difficulty of this type of engine was found to be in

governing economically at light loads or no load. The difficulty was met to some extent by the use of the Garret governing gear, but at light loads this engine was always somewhat higher in gas consumption than the Otto. This fact, combined with the higher consumption of the smaller engines, placed it at a disadvantage in the market, and led to its abandonment in favour of the Otto cycle when makers were free to use the latter. The engine ran very steadily and satisfactorily when properly proportioned, but great care had to be exercised in determining the proportions of pump and motor, and the shape of the passages and compression space, in order to secure the uniform discharge of the exhaust gases. Any error in these particulars led to the discharge of unburned gas at the exhaust-ports; and this was the reason why better results

Fig. 37.



12 N.HP. CLERK 1881 ENGINE, FULL LOAD DIAGRAM.

Diameter of cylinder, 9 inches; stroke, 20 inches; revolutions per minute, 132; I.HP., 27·46; consumption per I.HP. per hour, 20·39 cubic feet; consumption running light per hour, 90 cubic feet; B.HP., 23·21; consumption per B.HP. per hour, 24·12 cubic feet; mean pressure, 64·8 lbs. per square inch; maximum pressure, 230 lbs. per square inch; pressure of compression, 57 lbs. per square inch (Glasgow gas).

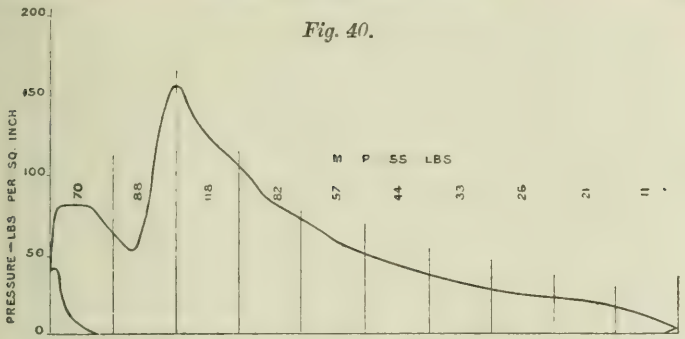
were obtained with large engines than with small ones. In the smaller engines it was hardly possible to avoid the discharge of some unburned gas at the exhaust-ports during the operation of charging.

In 1886 the Author built another engine at Birmingham of the same type as the 1878 engine, but differing from it in having no reservoir between the pump and the motor. This engine is shown in Fig. 38, Plate 5; a sectional plan through the cylinder, and an end view in part section, showing the arrangement of the levers, being given in Figs. 39.

A motor diagram and a pump diagram are given in *Figs. 40* and *41*.

Figs. 42 show the relative positions of the motor- and pump-cranks at different positions and at the moment of firing. This

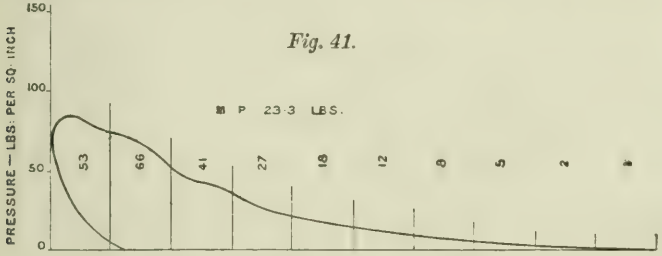
Fig. 40.



MOTOR DIAGRAM, CLERK 1887 ENGINE.

Cylinder diameter, 9 inches; stroke, 15 inches; revolutions per minute, 140; I.HP., 10·71 at 54·9 lbs. per square inch mean pressure (average of several cards); gas consumption per I.HP. per hour, 20·1 cubic feet; B.HP., 8·96; gas consumption per B.HP. per hour, 24·1 cubic feet (Birmingham gas).

Fig. 41.



PUMP DIAGRAM, CLERK 1887 ENGINE.

Figs. 42.

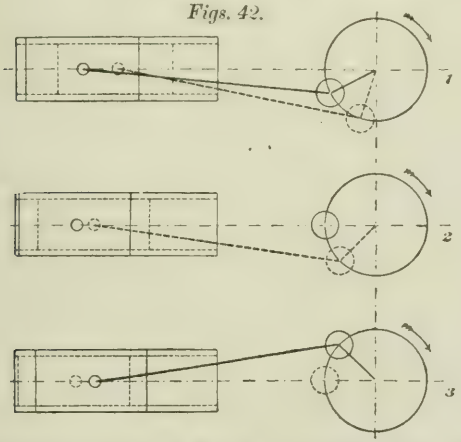


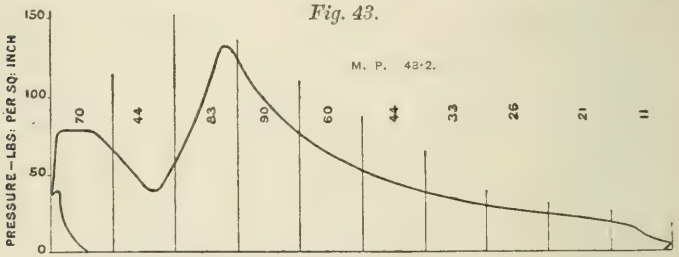
DIAGRAM SHOWING POSITIONS OF MOTOR AND PUMP, CLERK 1887 ENGINE.

The motor-crank and connecting-rod are shown in full lines and the pump-crank and rod in dotted lines; 1 is the position when the valve opens between motor and pump; 2 when the motor-piston is full in; and 3 shows the pump-piston full in and the motor-piston in the igniting position.

engine gave very economical results, and its running was satisfactory when the adjustments of the valves were accurately maintained. The difficulty of back ignition into the pump was overcome by diminishing the passage between motor and pump to the smallest possible volume. When back ignition did occur the engine was not materially affected, as the pump at once took in a new charge of gas and air, and, after compressing it, delivered into the motor cylinder as the piston moved on its forward stroke. The motor piston moved on to the end of the stroke, leaving only mechanical clearance, and so discharged the whole of the exhaust products.

The governing was accomplished by opening a special valve from the pump-cylinder to a reservoir of considerable capacity, closing the valve communicating between the pump- and motor-cylinders, and holding open the exhaust-valve during the exhausting and charging strokes. The effect of these operations was to

Fig. 43.



Motor Diagram, Clerk 1887 Engine (Firing late).

prevent the transfer of a charge from pump to motor; the pump-piston acting to compress and expand the charge to and from the governing reservoir, while the motor-piston alternately discharged the exhaust gases into the exhaust-pipe, and took them back to the motor-cylinder. The governing was economical.

The engine is too complex to compete with advantage with small engines, but is well adapted for large powers. It admits of any required compression and any required expansion of the gases after ignition; but, like large mill steam-engines of the Corliss type, it requires careful handling and attention. It is not suited for the rough work and unskilled attention which is given to small gas-engines.

To secure the best results, it is necessary that the ignition should follow the closing of the inlet-valve from the pump to the motor with extreme rapidity, as a short delay in firing causes considerable loss of power. This is shown by *Fig. 43*, where the ignition has occurred too late.

A considerable loss of power is thus caused by firing at a low instead of at a high compression. To obtain the best results from this type of engine, the stroke should be long in relation to the diameter of the cylinder. With a large engine with a cylinder of, say, 24 inches diameter, a stroke of 4 feet would be desirable; such an engine could readily be designed to give a consumption equivalent to 11 cubic feet of Birmingham gas per I.HP. hour. Eighty revolutions per minute would be a suitable speed for it. The engine would be arranged to give an impulse every revolution when light as when loaded. This type of engine has also been arranged by the Author to have a considerable clearance space at the end of the cylinder, which space should be swept out by pure air. With such a space, the difficulties of the engine are considerably diminished.

Figs. 45.

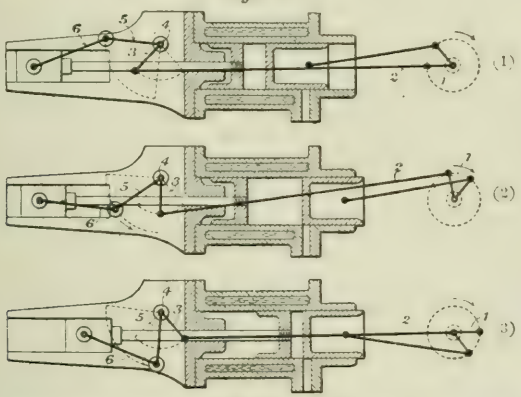


Diagram showing positions of Motor and Pump, Clerk 1887 Engine.

In 1889 the Author designed the engine illustrated in Figs. 44, Plate 5, and *Figs. 45*; and a small example of the type was constructed at Birmingham in 1890 for experimental purposes. Two pistons are employed in one cylinder; one, the trunk-piston, is the motor-piston, and the second is the charging- and exhaust-expelling piston. The second is operated by a piston-rod passing through a cover at the back of the engine-cylinder; this rod is attached to a cross-head working in guides, operated by a separate crank (1), connecting-rod (2), lever (3), rocking-shaft (4), and toggle-links (5) and (6). The motion is so devised that when the motor-piston is out and crossing the exhaust-port, the charging-piston moves out and discharges the products of combustion from the cylinder by the front exhaust-port. At the

same time it takes into the cylinder a charge of gas and air on the other side. The two pistons then move back together and the charge is compressed; after a time the charge passes from the back of the charging-piston to the front, and so occupies the space between the two pistons, and is ignited when the motor-piston is full in. The motor-piston then moves out under the pressure of explosion while the back piston remains practically stationary. This pause is brought about by the toggle-links crossing their centre, and it is sufficiently prolonged to enable the motor-piston to practically complete its stroke before the back piston begins to move.

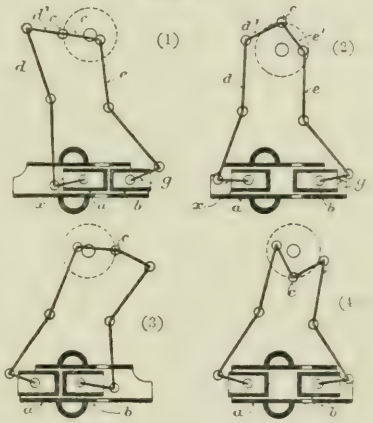
In the first position, *Figs. 45*, the engine is exhibited as when the mixture is ignited. In the second, the motor-piston is just overrunning the exhaust-port and the charging-piston about to move out. In the third, the piston has returned, closing the exhaust-port, and the charging-piston is fully out, having taken in its charge at the back of the piston and discharged the exhaust at the front; the first position is then repeated, when the charge is compressed and ready to ignite. This engine is, in the Author's opinion, well adapted for both moderate and large powers. It is simple and avoids all the difficulties of the impulse-every-revolution engines. It is capable of the highest economy possible in a gas-engine.

Before leaving this part of the subject it is necessary to shortly describe the work of Mr. James Atkinson, who has made a very determined effort to conquer the difficulties attending this type of engine. Mr. Atkinson's first gas-engine patent is dated 1880, but his first compression gas-engine was exhibited in 1884. It was designed much on the lines of the Author's 1878 engine, and the difficulties encountered by both were similar. Mr. Atkinson's first original solution of the difficulty of obtaining an impulse at every revolution in an explosion compression gas-engine was made in 1885, a vertical section of the engine being shown in Fig. 46, Plate 5. *Figs. 47* show the various positions of the two pistons which perform the operations of the cycle.

Two pistons a and b are connected with a common crank-pin c by levers $d\,e$, and rods $d'\,e'$; short links x and g connect the lower ends of the levers with the pistons. In the first position the exhaust is completed. In the second the piston a has moved away from the other one to take in the charge of gas and air. The piston b, in the next position, has followed a and compressed the charge, while in the last the piston b has moved out and expanded the gases after explosion. The engine is very ingenious, and performs all the operations of charging, compressing, exploding

expanding, and exhausting, in one revolution of the crank-shaft. A consumption of 25 cubic feet of London gas per brake HP. hour at full power was claimed for this engine by its designer. It was found, however, that the linkage was troublesome mechanically, and that the consumption of gas when running without load was high. The engine was capable of expanding the hot gases down to a low pressure, but a great disadvantage was found in the shallow compression space in relation to the diameter of the cylinder. A shallow compression space approximates too closely to an ideal condenser or cooler, and so an engine with such a space may lose more heat than is compensated for by the extra expansion.

Fig. 47.



Mr. Atkinson replaced this engine, which he called the "Differential gas-engine," by a very ingenious engine, Fig. 48, Plate 5, to which the name of the "Cycle Engine" was given. The engine marked a great advance on the differential engine, and in its expanding the hot gases a step was made in advance of any engine up to 1888 in point of economy of gas consumed. One of these engines was submitted to the Society of Arts in competition with the Crossley engine mentioned in the earlier part of the Paper, and was found more economical than the latter. *Figs. 49* show four positions of the piston and other parts. By following the movements it will be found that the whole of the operations of the Otto cycle are performed simultaneously with the expansion of the whole of the exhaust gases by one piston connected with the crank-shaft by a peculiar linkage. The engine is fully described in the Report of the Judges for the Society of Arts.[1]

It is true that in this engine an impulse was given to the crank-shaft for every revolution, but notwithstanding this the piston made four single strokes for each cycle of operation, so that, as far as the piston was concerned, the Otto cycle was followed. The

[1] Trials of Engines for Electric Lighting. Journal of the Society of Arts, vol. xxxvii. p. 213.

economy was gained by expanding to a greater volume than that existing before the compression of the gases.

Figs. 49.

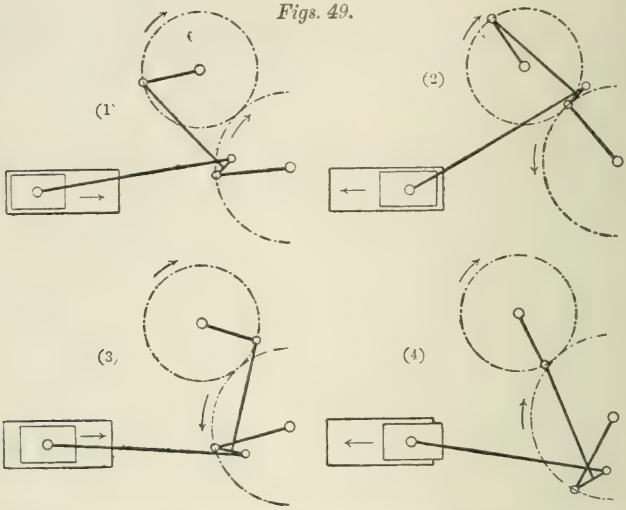
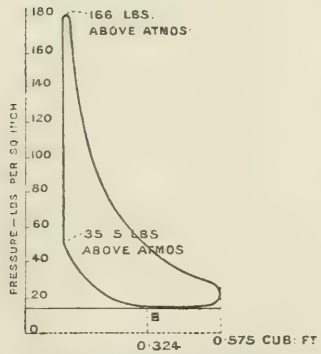


Fig. 50 is a diagram reproduced from the Society of Arts report, page 18, showing the Atkinson diagram. It will be observed that the compression pressure is only some 35·5 lbs. per square inch above that of the atmosphere, but while the volume at the point B is 0·324 cubic foot, the volume to which the gases are expanded before exhausting is 0·575 cubic foot. If the Atkinson engine had worked in the same manner as an Otto engine, using the same compression, then the exhaust-valve would have discharged the cylinder at the point B, so that the remainder of the pressure would have been lost. The volume of the compression space was 0·118 cubic foot, so that the ratio of the compression space to the volume 0·324 is as 1 to 2·74. The theoretical efficiency of this part of the diagram would therefore be

Fig. 50.



Atkinson Cycle Diagram.

$$E = 1 - \left(\frac{1}{2\cdot74}\right)^{0\cdot408} = 0\cdot33.$$

This efficiency is that of the lowest Otto result given on page 104, and the actual efficiency to be expected would be 0·15. The Society of Arts trials showed the actual efficiency to be 0·205,[1] so that the difference is due to the extra expansion. The consumption of gas in London was 18·82 cubic feet per I.HP. hour, by far the lowest consumption of that period.

The high piston-speed of the "cycle" engine during its expansion stroke, and the great expansion, both tended towards economy; but the relatively shallow combustion space made it desirable to keep down the pressure of compression, so the results which could have been obtained with high compressions and the same relative expansion were not produced. The engine had mechanical defects also which led to its ultimate withdrawal. The piston-speed was very high, and the joints were too numerous to secure complete commercial success.

The Author has rapidly traversed the leading points connected with Otto cycle and impulse-every-revolution engines. He proposes now to consider the modifications which may still be made in the indicator diagram of the gas-engine to further increase its heat efficiency. In this, the Otto cycle will be referred to, but it is to be remembered that the impulse-every-revolution engines may be arranged to produce any of the results brought about by the Otto engine. It has been pointed out that the actual indicated efficiency of a gas-engine increases with the theoretical efficiency, and that the actual efficiency varies between 0·45 and 0·58 of the theoretical efficiency. The indicated efficiency also increases with the dimensions of the engine, other things being similar, when the ratio of compression space—and therefore the theoretical efficiency—remains constant. Thus at page 11 an engine with a 9½-inch cylinder and 18 inches stroke, having a theoretical efficiency of 0·40, gave an indicated efficiency of 0·19 or 0·47 of that theoretically attainable. Referring to a careful test of a 100-HP. double cylinder Otto engine made in Philadelphia by Mr. H. W. Spangler,[2] it will be found that the cylinders were each 14 inches diameter by 25 inches stroke; the engine developed on an average 127 I.HP. and 92·5 brake HP. at 160 revolutions per minute. The clearance space was practically 28 per cent. of the whole volume of the cylinder, that is, 28 per cent. of the volume swept by the piston plus the com-

[1] Society of Arts figure corrected for heat of steam.

[2] Journal of the Franklin Institute, vol. cxxxv. p. 340, 3rd Series, No. 105.

pression space. The theoretical efficiency of such an engine is 0·41, but the actual efficiency was found to be 0·277, so that

$$\frac{0\cdot277}{0\cdot41} = 0\cdot675.$$

The actual efficiency, instead of being only 0·58 of the theoretical, rises to 0·675 of the latter, due to changes in the dimensions of the engine without practical change in the compression. The engine mentioned on page 11 as of 7 inches diameter by 15 inches stroke, gave an efficiency of 0·25, while the larger engine of 11½ inches diameter and 21 inches stroke, having a similar compression space, gave an efficiency of 0·275.

The theoretical efficiency in both cases is 0·428, and the ratios are

$$\frac{0\cdot25}{0\cdot428} = 0\cdot58 \text{ and } \frac{0\cdot275}{0\cdot428} = 0\cdot643.$$

The actual efficiency therefore increases with the dimensions of the engine, the compression remaining constant, as shown in the following Table:—

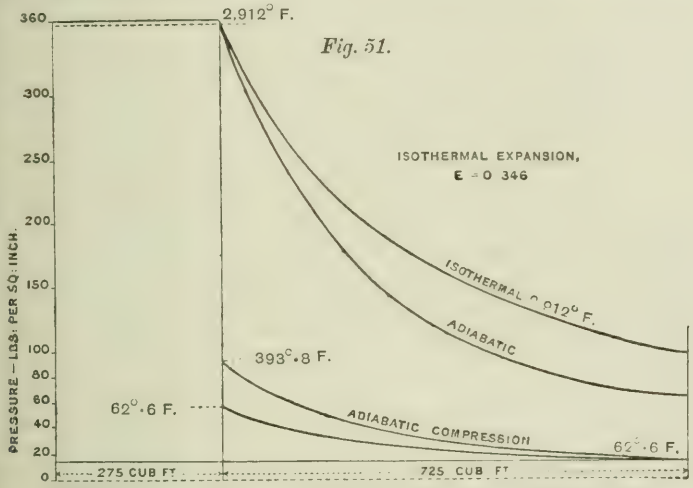
TABLE SHOWING COMPARISON OF THE ACTUAL AND THEORETICAL EFFICIENCIES OF OTTO ENGINES OF DIFFERENT DIMENSIONS.

Engine Cylinder.	Relative Capacity.	Theoretical Efficiency.	Actual Indicated Efficiency.	Rates of Actual and Ideal Efficiency.
Nearly equal compression — 7 inches diameter by 15 inches stroke.	1·00	0·428	0·250	$\frac{0\cdot25}{0\cdot428} = 0\cdot58$
Nearly equal compression — 11½ inches diameter by 21 inches stroke.	3·77	0·428	0·275	$\frac{0\cdot275}{0\cdot428} = 0\cdot64$
Nearly equal compression — 9½ inches diameter by 18 inches stroke.	1·00	0·40	0·210	$\frac{0\cdot21}{0\cdot41} = 0\cdot53$
Nearly equal compression — 14 inches diameter by 25 inches stroke.	2·97	0·41	0·277	$\frac{0\cdot277}{0\cdot41} = 0\cdot67$

There is, however, a limit to this increase of efficiency with increased dimensions. The increase in the efficiency of the larger engines as compared with the smaller using the same ratio of compression space is due to the diminished relative loss of heat from the gases produced by the explosion to the enclosing metal walls; and it is always found that in larger engines the expansion curve tends to rise more and more above the adiabatic line. With a maximum temperature of explosion of about 2,912° F.,

it is found by experiment that the actual increase of temperature due to explosion accounts for about from 0·6 to 0·7 of the total heat of the gas present. There is consequently heat enough present in a gas-engine of ordinary proportions, if none be lost, to maintain the temperature during expansion whilst performing work to the maximum 2,912° F. during the whole expansion stroke. This increase in dimensions, if carried to an extreme, could therefore only reduce the loss to insignificant relative proportions; and in such a case the mass of incandescent gas might be considered to lose no heat whatever to the walls of the cylinder.

Fig. 51.



THEORETICAL DIAGRAM. ISOTHERMAL LINES AND ADIABATIC LINES.

Efficiency of adiabatic compression and expansion = 0·409.

Work of adiabatic compression	3,414	foot-lbs.
Heat added for explosion	24,622	,,
Work of isothermal expansion at 2,912° F.	18,264	,,
Total heat added during cycle	42,888	,,

Consider an air-engine in such a case; the total volume of the stroke plus clearance space being 1 cubic foot. Assume the engine to have a compression space of 0·275 of the entire volume of the cylinder, then the diagram and results would be as shown in *Fig. 51*, when the temperature of explosion is 2,912° F.

From this it will be seen that while 0·409 is the efficiency for adiabatic expansion, 0·346 is the efficiency for isothermal expansion. Hence, it appears that, allowing for the known property of the suppression of heat in a gaseous explosion, the utmost efficiency possible for an engine using coal-gas, having a compression space 0·275 of the total volume of the cylinder,

and expanding to the same volume as existed before compression, is 0·346. So the efficiency actually attained in practice is $\frac{0\cdot277}{0\cdot346}$ *i.e.*, 80 per cent. of the possible value.

So far practice has shown that the absolute efficiency of the gas-engine has been increased from 16 per cent. in 1882 to practically 28 per cent. in 1895, and this great change in economy has been brought about by increase in compression alone. The pressure of compression has risen from 35 lbs. per square inch to 90 lbs. per square inch above atmospheric pressure.

The question arises how far can this compression be still enhanced? It will be observed from the formulas i. and ii. on p. 5 that the efficiency increases somewhat slowly at the higher pressures; and thus a limit must be reached beyond which the increasing weight and dimensions of the parts of the engine due to rising maximum pressure will more than counterbalance the improved theoretical economy.

Assume, for example, that a compression of 210 lbs. per square inch above that of the atmosphere is feasible; the volume of the compression space will then be 0·144 of the total volume of the cylinder, so that the theoretical efficiency of such an engine will be

$$E = 1 - \left(\frac{1}{6\cdot95}\right)^{0\cdot408} = 0\cdot546.$$

The ideal efficiencies for different compressions thus stand—

E = 0·33 for 38 lbs. per square inch compression above atmospheric pressure.		
E = 0·40 for 66·6	ditto.	ditto.
E = 0·428 for 87·5	ditto.	ditto.
E = 0·546 for 210	ditto.	ditto.

Such a compression as 210 lbs. per square inch would produce, with an explosion temperature of 2,912° F., a maximum pressure of 675 lbs. per square inch above atmospheric pressure; and this would involve an engine having working parts nearly double the weight of those of the engine tested by the Author at Messrs. Crossley's, with but a moderate increase in power for the great increase in weight. The Author accordingly considers a compression of 200 lbs. per square inch as considerably above the limit likely to be useful in an "Otto" gas-engine.

The gas-engine is now rapidly nearing the limit of advantageous compression, so that no considerable further economy is to be

expected there. In the diagram, *Fig. 2*, however, it may be observed that, at the moment of opening the exhaust-valve, there is still in the cylinder a pressure of about 50 lbs. per square inch above atmospheric pressure. It is obvious if the cylinder of that engine had been longer, and the piston could travel farther, that the pressure could have been reduced while the expanding gases were performing work on it. This source of economy has long been obvious, and many engineers have attempted to realize it in practice. The Author has calculated an ideal case of this kind in which the pressure of compression was 100 lbs. per square inch above that of the atmosphere, the explosion temperature 2,912° F., and the adiabatic expansion carried on far enough for the contents of the cylinder to fall to atmospheric pressure. The theoretical efficiency of such an engine would be 0·73, and, with an engine of about 200 I.HP., a practical efficiency of 0·73 by 0·6 = 0·438 is probable. Efficiencies of 45 per cent. of the whole heat given to the engine are now within reach.

The question, however, as to whether greater or less expansion should be utilized in an engine is altogether a matter of dimensions. For small engines, great expansion, beyond the volume of the charge before compression, is inadvisable; as the reduction of the volume of mixture dealt with at each stroke may easily so far increase the relative loss of heat to the cylinder, as to more than neutralize the gain obtained from the extra expansion. In very large gas-engines it will be undoubtedly advisable to adopt the compound principle, and many engineers have attempted it. So far, however, compounding has not proved successful. The principles involved are not yet thoroughly understood, and require further investigation.

Since 1876, when the largest gas-engine in Great Britain was of the old "Otto" and "Langen" type of 3 HP., gas-engines have increased in size to 400 HP., and from an efficiency of 12 per cent. to 28 per cent. The gas-engine will assuredly be yet applied upon railways and to ships, just as it is now being applied in factories; its principles are understood better than they were ever previously, and engineers are daily improving their knowledge of the properties of flame and the means of harnessing flame, instead of steam, to the great work of the world.

The Paper is accompanied by eight sheets of tracings, from which Plates 4 and 5 and the *Figs.* in the text have been prepared.

[Appendix.

APPENDIX.

Table I.—Composition of Coal and Cannel Gases. P. F. Frankland. 1882–4.[1]

Town.	Reputed Illuminating Power in Standard Candles.	Hydrocarbons. Cn.Hm.	Equivalent in Ethylene. C_2H_4.	Average Formula of Cn. Hm. or		Carbonic Anhydride. CO_2.	Oxygen.	Nitrogen.	Hydrogen.	Carbonic Oxide. CO.	Marsh Gas. CH_4.	Ratio of Illuminating Power Equivalent of C_2H_4 per Cent. or 1 per Cent. C_2H_4= Standard Candles.	Price per 1,000 Cubic Feet.
				Carbon Density.	Hydrogen Density.								
Edinburgh	30?	12·23	16·55	2·71	5·38	0·35	1·00	3·64	33·24	6·61	42 93	1·81	3*s.* 10*d.*
Glasgow	27	10·00	13·40	2·68	5·09	0·29	0·06	3·07	39·18	7·14	40·26	2·01	3*s.* 8*d.*
St. Andrew's	27	10·04	13·71	2·73	5·09	2·73	0·48	2·83	36·63	5·16	42·13	1·97	4*s.* 2*d.*
Liverpool	21½	7·90	9·50	2·41	5·09	1·70	0·19	6·10	36·44	3·39	44·28	2·26	2*s.* 10*d.*
Preston	20	6·22	8·41	2·70	5·09	0·84	0·25	4·79	43·95	4·62	39·33	2·38	3*s.*
Nottingham	18½	5·63	8·24	2·93	5·09	0·81	0·21	2·51	45·52	5·63	39·66	2·25	2*s.* 6*d.* to 2*s.* 8*d.*
Leeds	18	7·28	10·64	2·92	5·09	0·34	0·07	4·32	40·23	5·02	42·74	1·69	1*s.* 10*d.*
Sheffield	18	6·28	8·78	2·79	5·09	0·24	0·10	2·56	43·05	4·72	43·05	2·05	2*s.* to 2*s.* 4*d.*
Birmingham	17¼	4·76	6·28	2·64	4·29	1·50	0·36	10·10	40·23	4·05	39·00	2·75	2*s.* 3*d.* to 2*s.* 9*d.*
Bristol	17	4·58	7·77	3·39	4·29	1·50	0·27	5·11	44·57	4·77	40·70	2·19	2*s.* 8*d.* to 2*s.* 10*d.*
London—													
Gaslight & Coke Co.	16	4·41	6·58	2·98	4·32	1·50	0·26	5·95	47·99	3·75	37·64	2·43	3*s.* 2*d.*
So. Metropolitan Co.	16	2·92	4·42	3·03	5·16	0·09	0·26	3·19	53·14	4·11	36·55	3·62	2*s.* 10*d.*
Redhill	16	4·40	5·91	2·69	4·58	0·74	0·49	3·37	48·18	3·41	39·41	2·71	4*s.* 6*d.* to 5*s.*
Gloucester	16?	4·95	7·10	2·87	4·58	0·03	0·51	2·73	48·89	4·64	38·25	2·25	..
Newcastle-on-Tyne	16	3·62	5·00	2·76	4·58	0·28	0·23	5·29	50·50	3·37	36·71	3·20	1*s.* 10½*d.*
Brighton	14	3·76	4·60	2·45	4·62	0·03	0·23	2·07	51·62	4·14	38·15	3·04	3*s.* 3*d.* to 5*s.* 3*d.*
Southampton	14	3·09	4·90	3·17	5·20	0·07	0·39	2·53	53·59	3·59	36·74	2·86	3*s.* 2*d.* to 3*s.* 8*d.*
Newcastle-under-Lyme	15	4·53	5·67	2·47	4·58	0·08	0·11	6·22	46·31	3·74	39·01	2·65	3*s.* 6*d.*
Ipswich	14	4·53	5·82	2·57	3·77	0·06	0·12	10·84	43·26	2·46	38·73	2·40	3*s.* 6*d.*
Norwich	14?	3·26	4·85	2·97	3·40	0·27	0·14	3·03	59·79	3·40	36·11	2·89	2*s.* 6*d.* to 2*s.* 8*d.*

[1] "The Composition and Illuminating Power of Coal Gas." By Percy Frankland, Ph.D. A paper read May 5th, 1884, before the London section of the Society of Chemical Industry, "Journal of Gas Lighting," July 1st, 1884, p. 17.

TABLE II.—DATA CALCULATED FROM P. F. FRANKLAND'S ANALYSIS OF VARIOUS SAMPLES OF GASES.

Town.	Weight of 100 Cubic Feet at 14·7 lbs. Pressure per Square Inch.		Volume of 1 lb. Weight at 14 lbs. per Square Inch Pressure.		Heat evolved by 1 lb. Weight in British Thermal Units.	Heat evolved by 1 Cubic Foot at 14·7 lbs. per Square Inch Pressure.				Volume at 62·6° F. and 14·7 lbs. per Sq. In. Pressure, which evolves Heat equivalent to 1,980,000 foot-lbs., or 1 HP. for one Hour.
						At 32° F.		At 62°·6 F.		
	At 32° F.	At 62°·6 F.	At 32° F.	At 62°·6 F.						
	Lbs.	Lbs.	Cub. Ft.	Cub. Ft.		B.T.U.	Foot-Lbs.	B.T.U.	Foot-Lbs.	
Edinburgh	4·355	4·100	22·97	24·39	19,827	863	666,560	813	627,740	3·154
Glasgow	3·926	3·691	25·47	27·09	20,604	810	625,960	762	588,530	3·3643
St. Andrew's	4·182	3·937	23·91	25·40	19,600	820	633,030	772	595,890	3·322
Liverpool	3·908	3·679	25·60	27·18	19,551	764	589,770	720	555,490	3·564
Preston	3·533	3·326	29·13	30·07	20,471	703	54,268	681	525,720	3·766
Nottingham	3·435	3·234	29·11	30·92	21,375	734	567,040	691	533,830	3·709
Leeds	3·932	3·702	25·43	27·01	18,786	739	570,490	695	537,110	3·686
Sheffield	3·738	3·519	26·76	28·42	20,520	767	592,150	830	557,570	3·551
Birmingham	3·793	3·571	26·37	28·00	17,645	669	516,730	630	486,650	4·069
Bristol	3·485	3·281	28·69	30·48	20,945	732	563,750	687	530,640	3·713
London—										
Gaslight & Coke Co.	3·332	3·137	30·01	31·88	20,666	688	531,770	648	500,580	3·955
So. Metropolitan Co.	2·866	2·700	34·89	37·04	22,912	664	507,110	618	477,680	4·145
Redhill	3·160	2·975	31·65	33·61	21,906	692	534,480	652	503,320	3·934
Gloucester	3·172	2·986	31·54	33·49	22,282	707	545,560	665	513,790	3·853
Newcastle-on-Tyne	3·053	2·874	32·75	34·79	21,494	656	506,810	618	477,090	4·156
Newcastle-under-Lyme	3·151	2·966	31·74	33·71	21,548	679	524,250	639	49,361	4·011
Brighton	2·862	2·694	34·94	37·12	23,432	670	517,890	631	487,480	4·062
Southampton	2·852	2·431	35·06	41·13	23,369	666	514,730	568	438,760	4·153
Ipswich	3·500	3·294	28·57	30·36	18,963	665	513,530	572	483,250	4·097
Norwich	2·880	2·711	34·72	36·89	23,782	685	528,940	645	497,820	3·977

TABLE III.—PARTICULARS OF A 6 N.HP. CROSSLEY "OTTO" GAS-ENGINE (No. 4683) BUILT ABOUT 1881, AND OF A 9 N.HP. CROSSLEY "OTTO" GAS-ENGINE (No. 19,772) BUILT IN 1892.

—	6 N.HP. Engine, No.4, 683.	9 N.HP. Engine, No. 19,772.
Diameter of cylinder . .	8 inches . . .	$9\frac{1}{2}$ inches.
Length of stroke . . .	16 „ . . .	18 „
Volume swept by piston .	804 cubic inches .	1,275·8 cubic inches.
Volume of compression space	516 „ „ .	510 „ „
Volume of compression space / Volume swept by piston	$\frac{516}{804} = 0{\cdot}64$ . . .	$\frac{510}{1,275{\cdot}8} = 0{\cdot}4$.
Pressure of compression above atmosphere . .	31 lbs. per square inch	48 lbs. per square inch.
Maximum pressure of explosion above atmosphere	126 lbs. per square inch	200 „ „ „
Mean available pressure .	57 lbs. per square inch	81·5 „ „ „
Revolutions per minute .	164	160
I.HP.	9·0	19·25
B.HP.	6·75	15·75
Gas consumption per hour .	230 cubic feet . .	408 cubic feet.
„ per I.HP. „ „ .	25·5 „ „ . .	21·2 „ „
„ „ B.HP. „ „ .	34 „ „ . .	25·9 „ „
Theoretical efficiency of an air-engine	0·32	0·40
Actual indicated efficiency	0·159	0·175
Mechanical efficiency . .	0·75	0·82
Area of charge inlet port .	Slide-valve, 1·5 square inch . .	$2\frac{3}{8}$ inches diameter by $\frac{7}{8}$ inch lift, 4·43 square inches.
Inlet port setting . . .	To $\frac{1}{4}$ inch open when piston is on in centre and still open $\frac{1}{5}$ inch on outer centre . .	Opens dead on in centre; is held open on out centre, and closes when the piston returns $1\frac{1}{2}$ inch.

TABLE III.—*continued.*

—	6 N.HP. Engine, No. 4, 683.	9 N.HP. Engine, No. 19,772.
Exhaust-valve	$2\frac{1}{4}$ inch diameter by $\frac{3}{8}$ inch lift, 2·65 square inch	3 inches diameter by $1\frac{1}{4}$ inch lift, 7·06 square inches.
Exhaust-valve setting	Valve opens when piston is still 1 inch from out end of stroke, closes when piston has crossed in centre and has moved $\frac{1}{2}$ inch out	Valve opens when piston is still $2\frac{1}{4}$ inches from out end of stroke, and closes exactly on the in centre.
Ignition-valve setting	Ignition port is $\frac{1}{5}$ inch open when crank is on in centre. (Slide)	Valve $\frac{5}{16}$ inch diameter by $\frac{5}{16}$ inch lift. Opens $1\frac{1}{2}$ inch of stroke before compression is complete, *full* open $\frac{1}{2}$ inch before compression is complete. (Tube ignition.)
Charge velocity	244 feet per second.	128 feet per second.
Exhaust velocity	137 ,, ,,	81 ,, ,,
Piston speed	437 ,, minute	480 ,, minute.
Power absorbed charging and exhausting	0·65 I.HP.	0·64 I.HP.
Gas inlet-valve	$\frac{3}{8}$ inch diameter by $\frac{3}{8}$ inch lift	1 inch diameter by $\frac{3}{8}$ inch lift.
Gas inlet-valve setting	When piston has made $1\frac{1}{4}$ inch forward stroke valve opens.	When piston has made $2\frac{1}{2}$-inch forward stroke valve opens, and closes when piston has returned $1\frac{1}{4}$ inch.

Discussion.

Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said that many members present were, no doubt, also present thirteen years ago, when the Author read a very interesting Paper on the "Theory of Gas-Engines." At that time the gas-engine, although it had been studied for many years before, had only been a practical success, and made so by Otto, during the previous half dozen years. Probably there were not many members who would now invite a discussion of the theories advanced by them thirteen years ago on such a new subject as the gas-engine then was. Since that time some members on the Council side of the table had gone over to the majority—nearly 25 per cent. of the whole number—and their places had been taken by members from the general body, some of whom discussed the Paper at the time to which he referred. It would, he thought, be extremely interesting to hear what the views of the latter now were as to the great advance which had been made in the subject under discussion. They were greatly indebted to the Author for his courage in challenging criticism and the labour he had bestowed in bringing forward the same subject again after a period of thirteen years, and he therefore proposed that a vote of thanks should be accorded to him.

Captain Sankey.

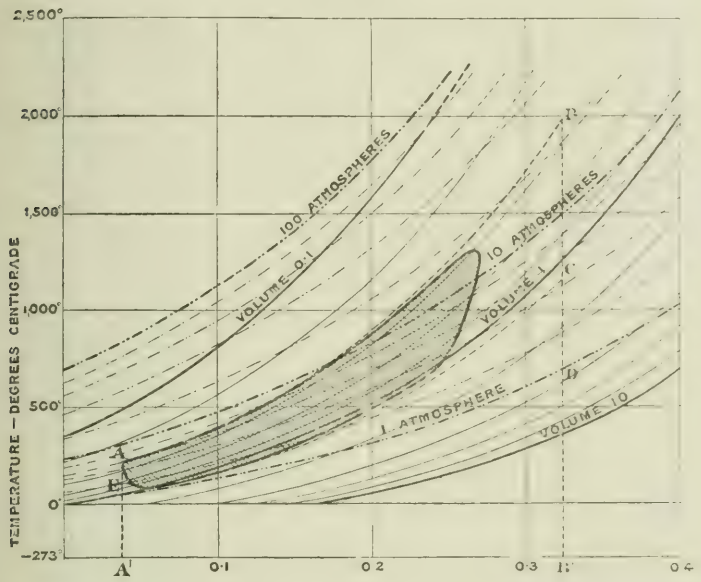
Captain H. RIALL SANKEY pointed out that a considerable portion of the Paper dealt with efficiency, and that the Author had given [1] an expression for the absolute thermal efficiency of an ideal gas-engine, working on the Otto cycle; and he would like to show how advantageously this question of efficiency could be dealt with by means of the $\theta\phi$ chart. The $\theta\phi$ chart for steam, as planned by Mr. MacFarlane Gray, was now well known, and evidently a similar chart could be prepared for any working fluid. The chart [2] for the gas resulting from the explosion in

[1] *Ante*, p. 98, and Minutes of Proceedings Inst. C.E., vol. lxix. p. 227.

[2] He had drawn this chart in 1893 for the products of combustion of the mixture given in "Gas- and Petroleum-Engines" by Prof. Robinson, pp. 299 and 372, viz., 1 cubic foot of coal-gas, 5·76 cubic feet of air and 4·5 cubic feet of products from previous combustions. The specific heats given by Prof. Robinson for this mixture were—$K_p = 0{\cdot}2581$ and $K_v = 0{\cdot}1889$. Recent experience, however, showed that the specific heat of gases was not constant, and increased considerably at very high temperatures. This would alter the shape of the $\theta\phi$ diagrams, more especially in the case of the ideal engines. Unfortunately, the data at present available was insufficient to warrant redrawing the constant-volume and constant-pressure lines. The unit volume was the volume of a kilogram of products at 0° C. and atmospheric pressure.

a gas-engine was shown in *Fig. 52*, and it would be seen that it consisted of a series of constant-pressure and constant- Captain Sankey.

Fig. 52.



volume lines, and that by their means the pressure, volume, temperature, and intrinsic energy of the gas could be ascertained

Fig. 53.

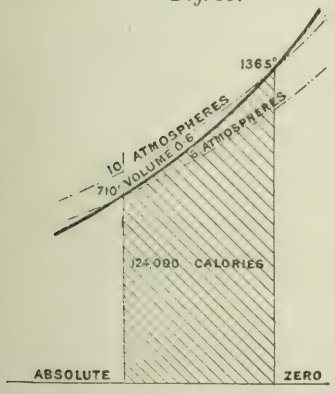
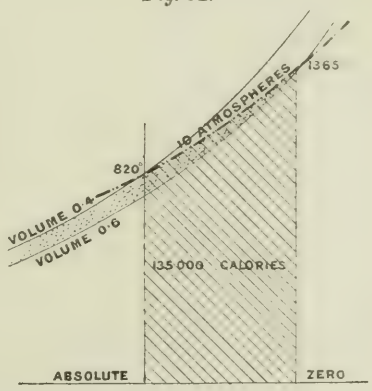


Fig. 54.



for any state of the gas. Moreover, the heat supplied or abstracted, as well as the work done by or on the gas in changing its

Captain Sankey.

condition from any state to any other state, could be determined by means of this chart. Thus, in *Fig. 53*, it was supposed that the temperature of one kilogram of gas was raised from 710° to 1,365° at constant volume. The pressure at the first state was read off the chart as 6 atmospheres, and at the second state as 10 atmospheres. The amount of heat added was represented by the shaded area, and was 124,000 calories. Clearly no work was done either by or on the gas. Again, in *Fig. 54* it was supposed that the temperature of 1 kilogram of gas was lowered from 1,365° to 820° at constant pressure. The volume in the first state was 0·6 cubic metre, and in the second state 0·4 cubic metre. The heat abstracted, namely, 135,000 calories, was shown by the shaded area, and the work done on the gas was represented by the area shaded by dots, contained between the constant-volume lines for 0·6 cubic metre and 0·4 cubic metre. Further, the intrinsic energy of the gas at any state was represented on this chart by the area bounded by the vertical drawn through the point representing the state, the constant-volume line drawn through the same point and the line of absolute zero temperature.

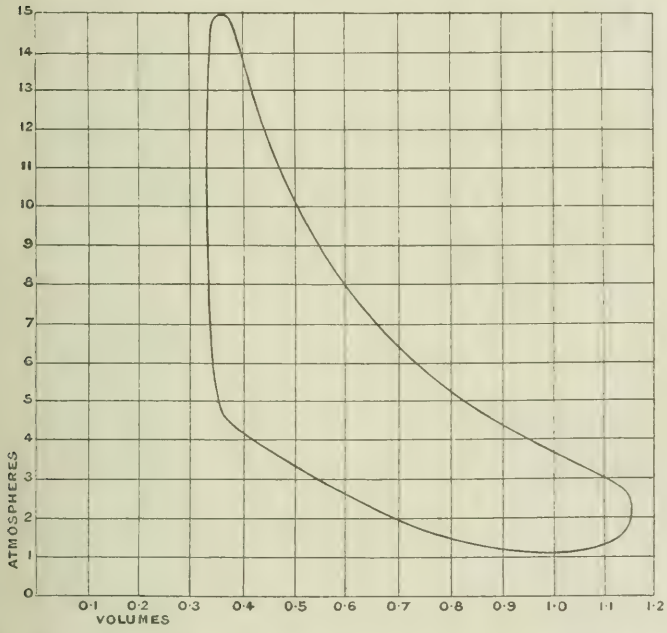
In *Fig. 52* A B C E was the $\theta\,\phi$ diagram of an ideal gas-engine working on the Otto cycle, and corresponded to the theoretical $p\,v$ diagram with adiabatic lines given by the Author in *Fig. 51*. The adiabatic compression of the charge was represented by E A; A B showed the rise of temperature at constant volume due to the heat produced by the explosion, the number of heat-units being represented by the area A′ A B B′; B C was the adiabatic expansion carried down to the original volume of the charge. The heat converted into work was evidently represented by the area E A B C, and thus the absolute thermal efficiency was $\frac{\text{area E A B C}}{\text{area A′ A B B′}}$, which it was easy, on the supposition of constant specific heat, to show[1] was equal to $\frac{\text{A E}}{\text{A A′}}$, or to $\frac{\text{T} - \text{T}'}{\text{T}}$, the expression given by the

[1] The absolute thermal efficiency of an element of the heat-supply X Z, Fig. 52, was— $= \frac{\text{X Z} \times d\phi}{\text{X Y} \times d\phi}$, but on the supposition that the specific heat was constant, the equation to a constant-volume line was— $\phi = \text{K}_v \log \frac{\theta}{\theta_o}$; hence $\text{X Z} = \theta\, \epsilon^{\frac{\phi}{\text{K}}}$ and $\text{Y Z} = \theta'_o\, \epsilon^{\frac{\phi}{\text{K}}}$, consequently the absolute thermal efficiency of the element was $\frac{\theta_o - \theta'_o}{\theta_o}$, a constant. The absolute thermal efficiency of the whole engine was therefore $\frac{\text{T} - \text{T}'}{\text{T}}$.

Author. If, however, the expansion were carried further than the original volume (as was the case in the Atkinson cycle and in others) this expression would no longer be true. Thus, if the expansion were carried down to atmospheric pressure, as referred to by the Author at p. 135, that was, to the point D, the number of heat-units converted into work was represented by E A B D, and the absolute thermal efficiency was $\frac{\text{area E A B D}}{\text{area A'A BB''}}$, which, for the case given in the Paper, namely, compression 100 lbs. per square

Captain Sankey.

Fig. 55.



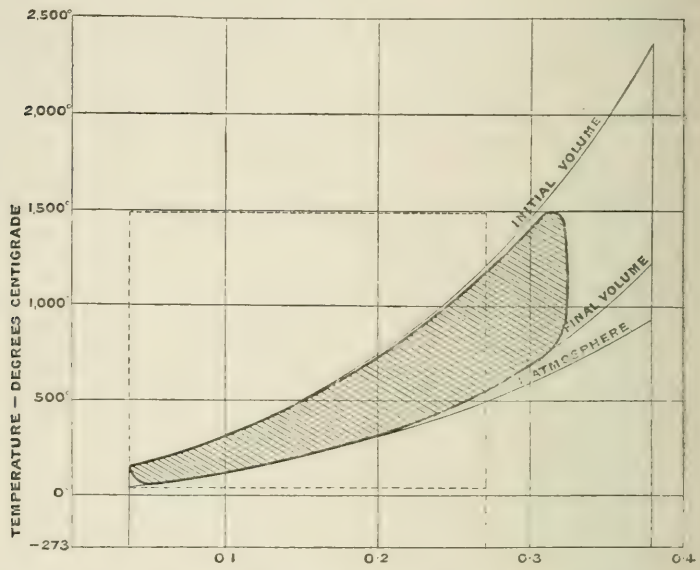
inch above atmosphere and explosion temperature 1,600° C., gave 54 per cent., considerably less than the figure given by the Author. He could not help thinking that there was an arithmetical slip in the Author's figure 0·73; if so, the absolute thermal efficiency of 0·44 for an actual engine was not yet within reach. He had worked out the $\theta\phi$ diagram of the ideal gas-engine expanding to atmosphere which gave 73 per cent. absolute thermal efficiency, and found that a compression of 90 atmospheres was needed.

The ideal diagram E A B C corresponded to the conditions under which the Otto engine at the Society of Arts trials was working,

Captain Sankey.

and shaded area was the $\theta\,\phi$ diagram of the actual engine derived from the indicator diagram given in *Fig. 55*; a comparison of these two enabled the losses to be localised. The ideal $\theta\,\phi$ diagram for

Fig. 56.



the Atkinson engine tried at the Society of Arts was shown in *Fig. 56*, the shaded area being the $\theta\,\phi$ diagram of the actual engine. The considerably reduced loss by incomplete expansion was very evident, and there was a noticeable improvement in the expansion line, which was practically adiabatic.

Fig. 57.

It was sometimes stated that the absolute thermal efficiency of the perfect gas-engine was about 80 per cent., an efficiency which was obtained by the formula $\frac{\theta - \theta'}{\theta}$. This implied working on the Carnot cycle, and required all the heat to be supplied at the higher temperature and all rejected at the lower temperature. The $\theta\,\phi$ diagram of a Carnot cycle gas-engine working between the temperature limits of 1,500° C. and 40° C. and supplied with the same number of

heat-units as the ideal Atkinson cycle-engine was shown by the dotted lines in *Fig. 56*, and the corresponding $p\,v$ diagram was given in *Fig. 57*. On the supposition that the explosive mixture remained gaseous at the enormous pressure to which it would be necessary to carry compression, it was unlikely that even an approximation to such a gas-engine could be designed, and, moreover, if designed, it would have practically no mechanical efficiency at all, owing to the enormous pressures required and the great range of expansion. The Carnot cycle was thus an impossible ideal for the gas-engine, and for this reason it was in his opinion a mistake to take it as a standard of comparison. Captain Sankey.

Professor W. C. Unwin thought the Paper an extremely valuable one, and he made the remark because he was about to offer a word of criticism upon it. Early in the Paper the Author had stated that Dr. Slaby and Professor Thurston had erroneously calculated the heating value of the gases used by deducting the heat of the evaporation of water produced by combustion. Whatever they had done they had certainly not made an error, an oversight, or a blunder. The fact was that questions as to the standard of efficiency were not questions of right or wrong, but merely questions of definition; and Dr. Slaby, Professor Thurston, Dr. Kennedy, himself, and others who had adopted that method of calculation were perfectly well aware of what they were doing. When there were conflicting definitions of the efficiency of an engine it was not, as he had said, a question of right or wrong, but a question of convenience as to which should be adopted. In the present case he wished to point out that in what was often called the total heat of combustion of 1 lb. of coal-gas calculated from data obtained by calorimetric experiments, there was not only heat which actually appeared as heat in the combustion, but a certain amount which appeared in condensing the steam produced. In the case of a gas-engine, that heat which in the calorimeter resulted from condensing steam did not appear as heat in the action of the engine at all. The steam passed away into the chimney, and it was one of the necessary losses of any gas-engine which had not a condenser. He therefore thought there was reason to do in the present case what was done in every boiler trial—to exclude the heat of evaporation of water produced as heat which did not appear in the action of the machine considered. It was worth making that protest, because so many memoirs had been written in which the same view was taken. No doubt rightly from his own point of view, the Author had adopted another definition and proceeded in another way, but it Professor Unwin.

Professor Unwin. was right to protest that experimenters who had acted otherwise had not committed any oversight. The Paper dealt specially with very modern improvements of the gas-engine, and in such improvements certain comparatively small sources of loss had been attacked with advantageous results. In the Atkinson engine the expansion had been extended, and in another engine the waste due to action during exhaust had been attacked. If the gas-engine were considered from the beginning, it would no doubt be first ascertained what was the big source of loss in it; and the one enormous loss in a gas-engine was the cylinder-wall action, which showed itself in the loss of a very large fraction of heat, amounting often to half the total heat produced, directly transmitted through the wall of the cylinder into the jacket. If that loss could be successfully attacked, it would result in very large economy. Was it possible that in any way that very large loss of heat through the wall of the cylinder into the jacket could be diminished? If he were in the way of taking out patents, which he was not, he should patent as an improvement on the four-stroke Otto cycle, which had so successfully established itself, a six-stroke cycle. It was known, in the case of air-compressors, that the effect of a water-spray in a cylinder was enormously more rapid and more effective than the action of a cold-water jacket. It was at least quite possible (he would not say that it would absolutely succeed, because experimenters with gas-engines knew that difficulties often arose which had not been foreseen) to have a gas-engine without a water-jacket and with a six-stroke cycle working in this way. There would be first the explosion-stroke and exhaust-stroke as in the ordinary cycle. Then a small amount of water would be sprayed into the cylinder, which would be evaporated by the hot cylinder-walls. That would give a steam-stroke in which some work would be developed at the expense of heat ordinarily rejected into the jacket. In the return stroke the steam would be discharged, and, lastly, there would be the ordinary suction- and compression-stroke. About $\frac{1}{5}$ oz. of water per stroke would carry off all the heat generated in the cylinder of a 10-HP. engine if evaporated. Hence about half this amount would do as much cooling as the ordinary jacket. Looking to the fact that for large sizes there would in time no doubt be double-acting gas-engines, in which the difficulty of cooling the cylinder-wall would be increased, he could not help thinking that the method of using fine water-spray, as in air-compressors, was worthy of consideration.

Mr. Donkin. Mr. Bryan Donkin remarked that nearly all the makers of gas-engines had now adopted the Otto cycle, and this fact diminished

the complication and difficulty of considering different cycles. That had not been the case a few years ago, because then twelve or fifteen different types had to be dealt with. Nothing had been said in the Paper as to analysing the exhaust gases. It was a very important point that the amount of oxygen, carbonic acid and carbonic monoxide escaping should be determined in order to ascertain the efficiency of the combustion. In some trials,[1] such measurements had been made. With regard to taking the temperature of the interior of the cylinder, this had now been rendered practicable by the instrument of Mr. Burstall, who used the Callender electrical-resistance thermometer, so that he was able to measure the temperature during the motor-stroke in the compression space of a gas-engine, either in the centre or near the walls. He thought that in comparing different gas-engines, it was very desirable that some recognised standard should be adopted. It was indirectly admitted by the Author that the thermal efficiency was the best standard, taking the brake HP. in preference to the indicated HP. as the useful work done. The thermal efficiency varied slightly, being rather higher with larger cylinders than with smaller. On that point he should like to have the Author's opinion. The experiment with the Crossley-Atkinson scavenging engine was very interesting and important. It gave the heat-efficiency of the engine as 27½ per cent. or 28 per cent., taking the I.HP.; and this compared favourably with 21 per cent. in the 1888 Otto engine. A very good case had been stated by the Author that the greater the compression the greater the economy, and the results of many experiments had been given to support that view. It would, however, be interesting to test the question of the long exhaust-pipe, by experimenting on two gas-engines of the same cylinder dimensions, running at the same speed, using the same gas, working with the same compression-pressure and initial pressure, but one having a long exhaust-pipe, and the other a short ordinary pipe. It was evidently the Author's opinion that the scavenging arrangements of Mr. Atkinson only increased the efficiency about 5 per cent.; but the expulsion of the products of combustion was a matter of importance. In modern gas-engines the clearance-space was gradually diminishing year by year, and particularly the clearance areas. He quite agreed with the Author that the extent of the latter should be very carefully considered, as it was in steam-engines. Of course, the less heat given up to

Mr. Donkin.

[1] "A Text-book of Gas-, Oil- and Air-Engines," by Bryan Donkin, M. Inst. C.E., London, 1894, pp. 366 and 391.

Mr. Donkin. the metal, the less there was to cool later, and the greater the economy. One advantage of the scavenging charge was that it diminished premature ignition, which, he believed, was troublesome in large motors. With regard to the Author's new design of 1889—a gas-engine with one cylinder and two pistons—he thought it very ingenious; but it was a matter of regret that no experiments were given. It would be interesting to know the results, if any had been obtained, in regard to thermal efficiency. The actual heat-efficiency of the best engines had been compared by the Author with the theoretical, or calculated heat-efficiency, and the one was only about half that of the other, so that there appeared to be a considerable field for future development. With reference to the question of the practical limit of compression, it could be judged from what the Author had stated that it might reach about 150 lbs. per square inch. The highest compression at present was about 90 lbs. per square inch, so that there was a possibility of still further economy. As a heat-efficiency of about 30 per cent. had already been obtained with the Atkinson-Crossley engine, perhaps at some future time the ideal figure of 40 per cent. might be approached. It remained, however, to be seen whether that efficiency was likely to result from a compound, a four- or a six-cylinder engine, and what cycle should be used.

Mr. Beaumont. Mr. W. Worby Beaumont noticed that in the early part of the Paper the Author had given figures relating to the very high power obtained from the new form of Crossley engine, known as the Crossley-Atkinson engine; but in one case he had given only the indicated HP. of the engine and in the other the brake HP. It would certainly be interesting to have both, with a view to ascertaining whether the mechanical efficiency increased with the indicated efficiency. In connection with one of his engines the Author had mentioned how certain great difficulties had been overcome. Difficulties in connection with back ignitions had been met finally by a modification of the form of the passage between the displacer-pump and the motor-cylinder, and this was a fact of much value, because such engines were in a sense very fickle, inasmuch as it was not known what would actually be the result of changes of that kind. In another part of the Paper the Author had referred to the question of the rapid conversion of the heat of the explosion into mechanical work by reason of the small space through which the piston moved when doing a large part of the total work. It was not, however, an advantage that the piston should move slowly at the time of the combustion and conversion. It would be better if the piston could move through a greater space at this period, and it

might be mentioned that some recent experiments with very high-speed engines had shown that more work was obtained from a given quantity of gas by increasing the speed of the engine. This showed that a greater amount of the heat of the explosion was converted into mechanical work when that conversion took place at a high speed, a fact which suggested another line of thought for the modification of the gas-engine in the future, besides that suggested by the Author in referring to the new type of engine that he had recently designed. He was glad to observe that the Author was not satisfied to consider the Otto cycle the ultimate standard, and that he had given good reasons for changing his engine, and to a certain extent returning to the type that he devised some years ago. The Otto cycle had given an exceedingly simple engine, and it had become possible to do with it that which had not been possible with any of the other forms, at all events as far as experiments had at present proceeded. But there were indications, some of which the Author had mentioned, that made it desirable to return in some respects upon some of the earlier designs, and if possible secure an engine which did not use three strokes out of the four for its own private purpose. With regard to the suggestion of Professor Unwin, it was questionable whether it would not lead him, in view of some of the experiments which had been made, to loss of time in the endeavour to obtain power from one of those six strokes, and also in view of several patents, which, to his knowledge, had been taken out for that purpose. Mr. Beaumont.

Professor Unwin asked whether Mr. Beaumont referred to experiments in which the steam was introduced into the cylinder or the water-spray. Professor Unwin.

Mr. Beaumont said he referred to experiments with water-spray by Mr. James Atkinson and Mr. H. P. Holt.[1] Mr. Beaumont.

Mr. Bertram Chatterton observed that the Author had stated that the impulse-every-revolution engines had been in competition with the Otto cycle for some years, and had fallen out of use; but the reason for that fact was not stated. He thought there must be some great difficulty in the question of heat passing away through the cylinder walls in an ordinary Otto cycle engine, where there was an explosion every two revolutions; the quantity of heat carried away was very great when the engine was working at full Mr. Chatterton.

[1] The proposal to use air compressed on one stroke in presence of or with a water-spray had also been made by Hargreaves, 1884; Willcox, 1885; Rollason, 1886; Butcher, 1879; Atkinson, 1881; Welch, 1883—all of whom had either used water-spray in one or other form or used a six-stroke cycle.

Mr. Chatterton.

power. The rate of transmission through the jacket was found in trials[1] by Professor Capper to be 886 thermal units per square foot per minute. The most severe transmission of heat observed in boiler trials[2] by Mr. Bryan Donkin and Professor Kennedy was in the Merryweather fire-engine boiler, where 10·5 thermal units were transmitted per square foot per minute. The figure 886 thermal units was estimated on the assumption that the greater part of the transmission occurred during the explosion stroke, which he did not think was true. The rate of transmission might be taken as 600 thermal units per square foot per minute, or about three times that in a very severely worked boiler. In a cylinder in which that great amount of heat had to be got rid of, serious difficulties would result in lubrication, in the working of the valves, or in some other way. Certain statements were made in the Paper as to the advantages to be derived from gas-engines from the size and shape of the clearance space. He had given some attention to that subject, and could not understand why the clearance space was not made spherical, or nearly so, decreasing the relation of the surface to volume to a minimum. He thought such a shape would result in a material economy. In view of the fact that the Otto cycle had been for many years in competition with almost every conceivable type of gas-engine, it must have some very excellent qualities. An engine working on the Otto cycle considered as a machine designed to stand great stresses, which were applied for an instant once in two revolutions, was no doubt very imperfect. The large loss of heat passing through the cylinder walls had been alluded to by Professor Unwin. In steam-engine practice the function of the steam-jacket was to keep the cylinder walls hot. He therefore alternated a gas-stroke and a steam-stroke in the same cylinder, using no jacket. He felt convinced that by a spray of water a cylinder could be kept in working condition. He had worked his engine hour after hour at the maximum power, and it was maintained at a uniform temperature by priming water in the steam, which he considered as a spray. The priming water would pass in through the valve and would be practically sprayed against the cylinder walls. He had observed the temperature by mercury in holes bored vertically in the sides of the cylinder. It worked five or six hours at a temperature of about 375° F., and did not become hotter. After work-

[1] "A Text-Book on Gas-, Oil- and Air-Engines," by Bryan Donkin, M. Inst. C.E., London, 1894, p. 355.

[2] *Engineering*, vol. lv. 1893, p. 114.

ing at the engine for about two and a half years he had abandoned it. In *Fig. 58* the admission of steam was shown and the admission of a compressed explosive mixture which was exploded at that point. The expansion of gas was to about two and a half times the original volume of the mixture before compression. The best results were about 14 lbs. of steam and 11 cubic feet of gas conjointly from each indicated horse-power, and about 18 lbs. of steam and 14 cubic feet of gas conjointly for each brake horse-power. The mean pressure of steam was 30·4 lbs. per square inch, and the mean pressure of the gas 28·4 lbs. per square inch. The explosive mixture was compressed to about 30 lbs. to the square inch, and the speed of revolution 120 per minute. It worked best at 120 revolutions, though he had worked it up to 180. The boiler-pressure was about 90 lbs. per square inch. The most serious difficulties in the design of the engine were the ignition of the

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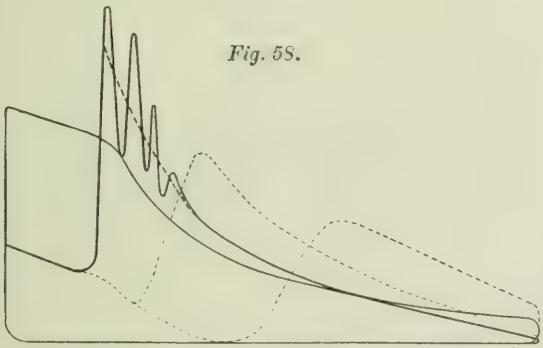

Fig. 58.

gaseous mixture, and the finding of valves suitable for carrying out those operations shown on the indicator card. A valve was required to hold up steam of 100 lbs. per square inch pressure, outside the cylinder, and to let it in at the right time. He had first tried slide-valves, but they were useless; he had therefore designed the one shown in *Fig. 59*. It was a mushroom valve with a balance-piston on the top consisting of a hollow casting of iron with about five grooves in it, its mean diameter being between the diameters of the inner and outer cone circles. The seating of the valve was about $\frac{1}{2}$ inch broad, and when it was shut, the area of the piston being greater than the area of the inner cone circle, it was perfectly tight, and there was no tendency to leakage. The valve was kept in equilibrium by a small $\frac{1}{4}$-inch pipe connecting the interior of the cylinder with the top of the piston, and, since the diameter of the outer cone circle was greater than that

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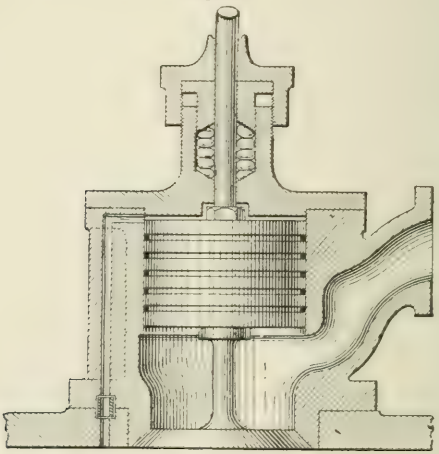
of the piston, the valve remained perfectly tight under an explosive pressure within the cylinder. He found that a valve of this design worked remarkably well for both the gas and steam operations depicted on the card. There was one golden rule in gas-engine design, that all surfaces should be reduced to a minimum; and this had been well carried out by the valve shown. It was very like an ordinary double-beat Cornish valve, only the upper delivery of a double-beat Cornish valve was entirely suppressed, and the whole valve presented to the working cylinder practically the best possible surface. The Author had referred, on p. 126, to the necessity for an ignition apparatus of extreme rapidity. He had tried many forms of ignition apparatus, and finally found that the most in-

Fig. 59.



Scale ¼ full size.

stantaneous was an electric one, the current being derived from a Ruhmkorff coil giving a continued succession of sparks in a tiny box covered by a valve which was opened suddenly. As far as he had grasped the problem of gas and steam, it seemed impossible to ever bring it to a practical solution, for the reason that a condenser on the steam could not be used on account of the air which was entrapped in the clearance spaces. It had been stated by Professor Robinson[1] that if a compressed mixture which was expanding was exploded, the inflammation and explosion was extremely rapid. One of the greatest defects in his engine was the shock which was produced; the explosion was

[1] Minutes of Proceedings Inst. C.E. vol. cxvi. pp. 246, 247.

an extremely violent one. He was aware that the shape of the clearance space had some influence upon it, but he agreed with Professor Robinson that the inflammation was solely due to the violent commotion of the gases. That was an irremediable defect in any engine. It had been shown by the Author that the efficiency of the Otto cycle gas-engine was now 80 per cent. of its full theoretic value. That was allowing for the "miss-fires" which took place in all gas-engine explosions. There were two qualities about the Otto gas-engine which certainly differentiated it from all competing types, and which had more to do with its commercial success than any others, viz., the very high ratio of positive to negative work in the cycle, being about 4 or 5 to 1, and also the very high mean pressure. Before such a cycle could be improved on it was necessary to find the desirable qualities to be remedied in the engine as it now existed. It would probably be desirable to alter the very high initial pressure, and also the suddenness of its application, because if these changes of pressure could be undergone more gradually, a great deal of weight now used in the Otto engine could be dispensed with and its field of usefulness extended, say for marine purposes, where the conditions of working were absolutely different from intermittent land work. In a marine engine idle strokes could never be afforded. As a matter of fact, the Otto engine was never set to work on the Otto cycle; for in its very method of governing, it missed strokes and did not work on the Otto cycle. Every stroke a gas-engine missed exercised a very material cooling action inside the cylinder, and it was necessary to thoroughly study the temperature and the radiation of heat through the walls of the cylinder before a satisfactory impulse-every-revolution engine could be designed. A constant-pressure diagram for 1 lb. of air was shown in *Fig. 60*. The gas was burned at a pressure of 150 lbs. per square inch. It was either adiabatically compressed up the line EA^1 to a temperature of 1,076° absolute F., or it might be compressed isothermally up the line EA, remaining at a constant temperature of 521° absolute. Its temperature was then raised to 2,293° absolute F., or 1,000° C., the maximum reached in the engine. The chief things to be borne in mind were to have a high ratio of positive to negative work, to have a high mean pressure, and to limit and control the maximum temperature. An engine working on such a cycle as that seemed an improvement on the Otto, because the maximum temperature was limited to 1,000° C., whereas in the Otto cycle it was 1,600° C. The explosion could be carried either to the point C', *Fig. 60*, which was to the

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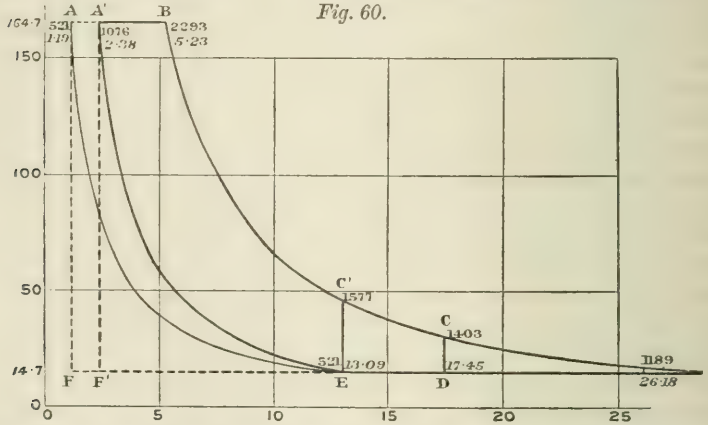
original volume, or to the point C, which was an expansion to 33⅓ per cent. beyond the original volume and to a temperature of 1,403° absolute. The regenerator had generally been discounted by engineers, but here was a clear case where it could be used, although not to save a great deal of energy. The compression outside the cylinder could be isothermal, and could be regenerated by the temperature of the exhaust gases; so that, supposing expansion finished at the point C, where the temperature was 1,403°, it would clearly be possible to regenerate the isothermally compressed gas to 1,075°. The great advantage of the regenerator would be that one of the commercial features in the Otto cycle would be retained and a higher mean pressure realised than with adiabatic expansion. The isothermal compression E A absorbed,

Fig. 60.



per lb. of air, 41,750 foot-lbs. of work; the adiabatic compression E A^1 absorbed 46,400 foot-lbs. The heat supplied in the first case was 420 thermal units per lb., and in the second 284 thermal units; or, expressed in foot-lbs., for the first 324,000 foot-lbs., and for the second 219,000 foot-lbs. The following Table had been deduced from the *Fig.*:—

Diagram.	Energy given out per lb. of Air.	Mean Pressure.	Efficiency.	Ratio of Positive to Negative Work.
	Foot-Lbs.	Lbs. per Sq. In.	Per Cent.	
A B C D E . . .	137,400	58·7	42·3	3·28
A B C^1 E . . .	124,000	72·3	38·2	2·97
A^1 B C D E . . .	107,200	49·3	49·0	2·30
A^1 B C^1 E . . .	93,850	60·8	42·8	2·02

More power and a higher mean pressure were obtained when isothermal compression was adopted, though at reduced efficiency if no regenerator were adopted. If a regenerator were applied to the first case in above Table the efficiency would be no less than 62·7 per cent. The Paper was particularly interesting because the Author stated his opinion of some years ago, and his present opinion, and his hopes for the future. He had said that, in common with the late Sir William Siemens, he considered that the constant-pressure gas-engine would be likely to show good results, but that he was now of opinion that for moderate powers and very large powers an impulse-every-revolution engine would give a good result, his idea for the future being that by some principle of compounding, an engine could be obtained with far greater efficiency than that of the engine in its present condition. He had not, however, stated his reasons or the difficulties that stood in the way. Mr. Chatterton's opinion was that the future of the gas-engine would not be evolved by taking ideas from steam-engines, their pistons, or cylinders. The last invention of Mr. James Atkinson was a proof in that direction. Taking the gas-engine of the present day, with a terminal pressure of 50 lbs. or 60 lbs. per square inch, he had shown that a practical benefit was obtained by allowing the engine to exhaust into a long pipe, and in that way introducing fresh air into the cylinder. The difficulty in gas-engine work was the great heat; it was impossible to design valves or any mechanism to control gas at such high temperatures as 1,000° C. or 1,600° C. He thought a gas-engine could be made on the constant-pressure principle, which involved certain advantages not alluded to by the Author. One difficulty that he had mentioned was, in these engines, the introduction of the charge into the cylinder, and there were also the difficulties of the reservoirs. Those could be entirely overcome by having separate pumps for the air and for the gas; and by a valve of special design the charges could be introduced into the cylinder and fired without passing back into a reservoir, so nullifying the succeeding two or three charges. He had overcome similar difficulties in his alternate steam- and gas-engine. In working with the Otto cycle, also, there was a fixity of the range of temperature which could be adopted; and this was occasioned by the limitations on the quantities of gas and of air that would explode. It was quite possible, working with the constant-pressure cycle, to have any desired temperature by burning just sufficient gas for the purpose. With large engines and more complicated mechanisms the temperature

Mr. Chatterton.

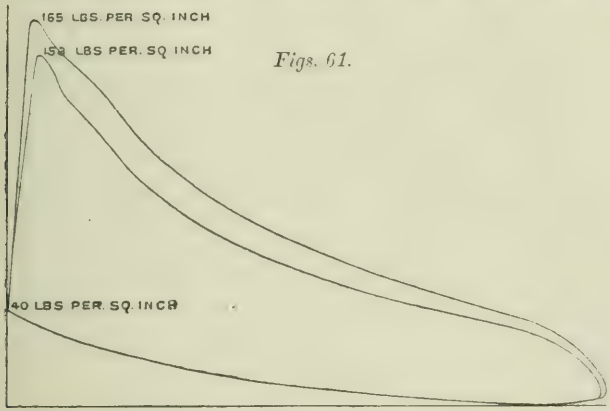
Mr. Chatterton. would be more under control. There was also the fact that with a gas-explosion 30 per cent. of the heat was not evolved at the proper time. Working with a constant-pressure cycle, that fact would not militate against efficiency. The mean pressure, in the second case, of 72·3 lbs. per square inch, with an efficiency of 38 per cent. ought to be commercially quite as good a cycle to work with as the Otto under its best conditions. The result would be, that on the one hand, if the temperature was increased, the losses in the cylinder were also increased; on the other hand, if the temperature was diminished, the ratio of positive to negative work diminished. Therefore an engine designed on this method of working would have to be a compromise between the above two conflicting qualities.

Mr. Dowson. Mr. J. E. Dowson agreed with the Author that much economy was due to the increase of pressure which had been given to the explosive mixture before ignition. At the same time, he was somewhat surprised to find that the Author stated with regard to scavenging, that he had never been able to credit it with more than 5 per cent. of economy as compared with the same engine working at the same compression, and retaining the exhaust-gases. In dealing with this subject in a Paper[1] some three years ago, he had mentioned that Mr. Atkinson had made an instructive experiment with one of his Cycle engines, working with ordinary town gas. He had a connecting-rod that could be fixed to two different centres—one capable of driving out all the products of combustion, the other leaving a space equal to about 30 per cent. of that occupied by the charge of gas and air, the compression being the same in each case. In that way he had found that, in the same engine with similar gas, and with other conditions constant, the consumption of gas was 25·7 cubic feet per B.HP. when not scavenging, and 22·11 cubic feet per B.HP. when scavenging, a saving equal to nearly 14 per cent. Another trial he might mention was that with a Premier engine, and Messrs. Wells Brothers had sent him two sets of diagrams taken by them with generator-gas made with coke. One set, from a non-scavenging Otto, gave an average mean pressure of about 50 lbs. per square inch. The other set was taken from a scavenging engine, in which the diameter of the cylinder, the stroke and compression, were the same as in the engine of the first set; that gave an average mean pressure of 67 lbs. per square inch, or an increase of 34 per cent. It was possible that the two engines were not working under

[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 2.

precisely similar conditions in all other respects; but whether or not, it was clear that considerable saving resulted from the scavenging. He had also been able to find some diagrams of his own, taken so long ago as 1881, with generator-gas made with anthracite, for the purpose of ascertaining the effect of scavenging as compared with non-scavenging. Those diagrams were taken on an engine of the Otto type, fitted with a pump which delivered air into the compression-chamber whilst the exhaust-valve was open, so that the residual products could be displaced by air. The engine would work with or without the pump. Two typical diagrams taken on the same day and with gas of the same quality were shown in *Figs. 61;* the smaller one represented the non-scavenging effect, and had a mean

Mr. Dowson.



Figs. 61.

Scale $\frac{1}{4}$th.

pressure of 57·8 lbs. per square inch, the larger card showed the effect of scavenging and had a mean pressure of 68·5 lbs. per square inch. The same volume of gas was used for each explosion in both, and the compression, before ignition, was identically the same. Therefore he thought he was correct in saying that the increase of the mean pressure due solely to scavenging was 18·5 per cent. Other trials which had come under his notice gave further confirmation of the fact that scavenging alone effected a greater saving than the 5 per cent. named by the Author; but one advantage of the scavenging was that the mixture of gas and air was not diluted or stifled with residual products of combustion, so that the oxygen of the air was closer to the combustible gas with which it had to combine; and he believed that a scavenging engine gave more complete combustion. Little

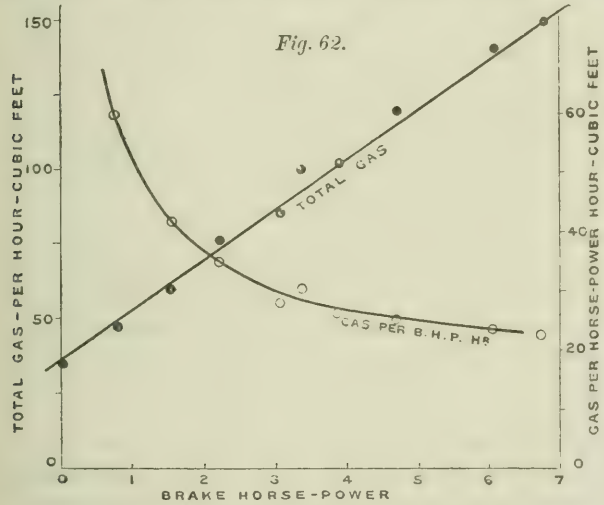
Mr. Dowson. was known of the exhaust products from an engine, nor was the air which was introduced into the cylinder measured, and these points should be dealt with in all careful investigations. In nearly all cases an excess of air was present in the cylinder, and no doubt it carried away with it some heat from the engine at the time of the exhaust, but the amount of that excess was, especially under varying loads, uncertain. A trial made in America in 1883, in which an air-meter had been used was, so far as he knew, the only case in which the air had really been properly measured. When high compression was used, the initial pressure on explosion was raised and was clearly a gain. The high compression also brought the molecules of the gases closer together and doubtless quickened the burning. He had no doubt also that it gave more complete combustion before the exhaust occurred. In that respect probably the high compression partly fulfilled the function of scavenging, but the example given in the Paper of the Stockport engine merely showed the effect of raising the compression from 60 lbs. to 90 lbs. per square inch without scavenging. What might have been the effect if there had been scavenging also was not known. The commercial value of scavenging largely depended upon its being effected without troublesome complications in the design of the engine and on the friction not being sensibly increased. The system adopted in the Crossley engine, described in the Paper, satisfied those conditions, and, apart from the saving effected in the gas consumption, it had a great practical advantage in cooling the engine, which for large powers was a very important consideration.

Prof. Beare. Professor T. Hudson Beare said the Paper was mainly devoted to the question of the possible and actual theoretical efficiencies of gas-engines, and as a consequence of the gas-consumption per HP. hour. Dealing first with gas-consumption, the Author had shown how that quantity had steadily decreased during the past thirteen years from 23·0 cubic feet in 1882 to 13·6 cubic feet in 1894. These remarkable figures fully deserved attention, and every credit should be given to those who had been working at the development of gas-engines during that time for the excellent economy they had obtained; but he was afraid unless engineers fully recognised that those figures were gas-consumption when the engines were working at full power they would be led into serious mistakes as to the cost of the power. In order to bring out that point he had made eight or nine trials with a small Crossley tube-ignition engine of 4 N.HP., and three or four years old, measuring the B.HP. and gas-consumption, and the results

were shown in *Fig. 62*. The load varied between 0 and 7 HP., and the amount of gas per B.HP. hour was shown. It was very large at a low power, and decreased considerably at the higher power. The actual figures were 22·3 per HP. hour at full power, and 58·6 cubic feet at about 1 HP. The speed and all other conditions were kept fairly constant during the trials. The other curve showed the total gas consumed per hour, and it would be noticed that the relation was expressed by a straight line, the well-known Willans law which applied to gas-engines as well as steam-engines. If users obtained their gas-consumption running light and at full power, they could at once obtain the gas-consumption at any intermediate power. Most of the gas-engines

Prof. Beare.

Fig. 62.



were only occasionally run to full power, and it was well therefore to remember that they were not getting their power quite as economically as would appear from the efficiency given for the full-power trials. This matter was well worthy of attention, because he had seen a query from a gas-engine user, asking if he was right in calculating the cost of his power by dividing the total number of cubic feet of gas used in three months by the product of the number of hours the engine ran, by the full HP. of the engine, but this would not be nearly correct. As to mechanical efficiency, the Author said that the "best gas-engines were now both from the mechanical and the heat-engine standpoint highly efficient machines." He had plotted out the mechanical efficiency for all the records given in the Paper, and many others, and he found a

Prof. Beare. surprisingly close agreement between all gas-engines of the Crossley type. If efficiencies were plotted to a base of indicated power it would be found that they would lie in almost an absolutely straight line, inclined at such an angle to the base that the average efficiency was 85 per cent. Now 85 per cent. of mechanical efficiency for a small engine was very good, but for very large engines it was not very good. When in engines developing 100 HP. 15 HP. were spent to drive the engine that was not a very good figure. It was even worse in some gas-engines. For instance, a "Simplex" gas-engine tested by Prof. Witz showed the I.HP. was 110, and the B.HP. 75, the mechanical efficiency in that case falling a little under 70 per cent., so that with 110 HP., they were using 35 HP. to drive the engine. As to thermodynamic efficiency, Captain Sankey thought the Carnot cycle should not to be taken as the standard of comparison with the gas-engine, because it was a practically impossible cycle. Granting that, at the same time if any real advance was to be made in gas-engines in the future, it was a grave mistake to conceal the fact that the gas-engine as at present worked with the Crossley cycle made little or no use of the range of temperature placed at its disposal. Taking the figures of the Crossley engines tested at the Society of Arts trial, the maximum temperature reached in the engine according to Dr. Kennedy's calculation was 3,440° absolute, and therefore the range of temperature available was between 3,440° absolute and 650° absolute. If the efficiency was what the Author stated, which was no doubt nearly true, only the very small range of temperature from 1,064° absolute to 650° absolute was used, and all the rest was wasted. He did not think, therefore, the gas-engine could be regarded as a perfect thermodynamic machine. The steam-engine suffered from the same drawback; it did not make use of all its range of temperature. Taking the very remarkable trial of the Cornish engine recently recorded,[1] the maximum range at the disposal of that engine, between the temperature of the steam and the temperature of the hot well was 254°, which was very small compared with the gas-engine range. On the other hand, the actual loss, 47°, in the cycle adopted was very small. It appeared to him that if that fact were put aside, the advance would not be made in the gas-engine which ought to be made. With regard to the jacket-water, and the amount of heat sent away in it, there appeared to be some misapprehension as to that point. Taking the results of the Society of Arts trial, the amounts

[1] *Engineering*, vol. lxi. p. 129.

of heat turned into useful work, rejected in the jackets and sent away in waste gases were 22·1 per cent., 43·2 per cent. and 35·5 per cent. respectively. The large amount rejected in the jackets seemed to a good many engineers to point to a possible economy. He considered it could not be done as long as the present cycle was used, because taking the principle of the gas-engine to be what it was, 39·9 per cent. represented all the work it was possible to get out of that heat, and the remainder must be thrown away, it did not appear to be a matter of consequence whether in the jacket or in the exhaust gases. Prof. Beare.

Mr. James Atkinson could not agree with the Author in his estimate that only 5 per cent. of the increased economy was due to scavenging. He thought the particulars given in the Paper were sufficient to show a much higher economy. Those of the Stockport engine showed that at 60 lbs. per square inch pressure the consumption was 22·3 cubic feet per B.HP. Calculating its consumption if its compression were increased to 90 lbs. per square inch in the manner explained in the Paper, he found it should give a B.HP. for 20·6 cubic feet, assuming its actual efficiency increased in direct proportion to its ideal efficiency. It actually took 20·75 cubic feet, a somewhat greater consumption. A different result would be found in column 3 of the Table on p. 104, showing theoretical indicated efficiency of Crossley-Otto engines with different compressions, compared with actual indicated efficiencies with the same compressions. The three first lines relating to non-scavenging engines showed at the best a ratio of 0·48 between the actual efficiency and the ideal efficiency corresponding to the compression used. The fourth line gave the particulars of the scavenging engine tested by the Author, and the ratio increased to 0·58, one-fifth better than would otherwise have been expected, even after full allowance was made for the increased compression, which was 87·5 lbs. per square inch. Also, notwithstanding its being a much smaller engine than the Stockport, it consumed 3·75 cubic feet less per B.HP., though the Stockport engine worked with the higher pressure of 90 lbs. per square inch. If nothing was gained by scavenging, but by compression only, why did 90 lbs. per square inch on the Stockport not show better results than 87·5 lbs. on the scavenging Otto? It appeared that the 5 per cent. was a very much lower estimate than the actual figures warranted. Very careful experiments had been made at Openshaw to ascertain the direct advantage of scavenging, and it was found that the shape of the combustion chamber, and many other conditions, had a considerable effect upon the results. Mr. Atkinson.

Mr. Atkinson. In one instance a 14-HP. engine had been tested, all conditions being kept exactly constant, excepting that in one set of tests scavenging was used and the other it was not. The compression in both instances was 80 lbs. per square inch. The non-scavenging engine developed 36·53 B.HP. with 20·03 cubic feet per B.HP., while the scavenging engine gave 39·91 B.HP., with 16·489 cubic feet per B.HP. A 7-HP. engine, with a compression of 70 lbs. per square inch, gave without scavenging 14·54 B.HP. with 20·3 cubic feet per B.HP. per hour, and in another instance 17·2 B.HP. with 21·2 cubic feet per B.HP. per hour. The same engine with scavenging gave 18·9 B.HP. with 17·8 cubic feet; and 16·06 B.HP. with 17·6 cubic feet per hour. Both those instances showed a very material saving, very much greater than the 5 per cent. mentioned by the Author. It was fully realised, as the Author had mentioned, that the scavenging improvements were of great importance with large engines, especially when working with Dowson gas.

With every gas-engine there was a certain possible maximum strain, which was considerably higher than the normal working strain. The greatest strain as a rule upon a gas-engine occurred when it was not working properly. If it missed ignitions and finally ignited a charge, rich in gas, mixed with pure air only, and cold, so that it was of the greatest density, very high initial and mean pressures were obtained. The strength of all the parts of the engine must be sufficient to resist with safety those maximum strains which were absolutely dependent on the size of cylinder and the amount of compression. Non-scavenging engines worked habitually very much below those maximum strains, in many instances less than one-half; consequently such engines had to be made very much stronger than was necessary to stand regular working loads. Scavenging engines had higher working loads, still much below the maximum which had to be provided for, and consequently the materials of which they were constructed were more economically disposed, the engines had a greater mechanical efficiency, occupied less space, were more easily started, and cost less. The scavenging of pure cold air cooled the passages and cylinder, extinguished any smouldering flame, prevented the ignition of a fresh incoming charge, and largely prevented pre-ignition from high compression. With the advantages of scavenging it was possible to make gas-engine cylinders at least twice as large as without. At the present time gas-engines were very strongly inclined to increase in size, and that was an important advantage. There was another point in connection with the passing of cold air through the

end of the cylinder, namely, that for every 5½° F. the charge in the cylinder was reduced in temperature before commencing to compress it, 1 per cent. more power could be obtained from the engine. No doubt the advantages of scavenging were partly due to the greater density of the charge; after compression and ignition the maximum and working temperatures were much lower and the gas was more thoroughly and completely burnt, and, especially in the earlier parts of the stroke, ignition was more certain and regular. Also the regular working strains more nearly approached the maximum referred to. It had also been proved by very careful experiments with a scavenging engine that it was possible to work more economically the higher the temperature of the cooling water. Gas-engines hitherto had always been compelled to work at a temperature of the cooling water very much below boiling-point, but with scavenging engines, when properly arranged, the economy increased to the boiling-point of the water, and the engine worked as satisfactorily when the water was actually boiling as it did at any other temperature. That was a point which might possibly be of great advantage where the amount of available water was not very great. He was fully aware of the economy to be obtained by increasing the compression; at the same time it was a point which must be dealt with somewhat carefully. The mere fact of saving a cubic foot of gas per brake HP. was insignificant compared with the fact that the engine must be absolutely reliable and stand the wear and tear of every-day use. Caution was necessary in dealing with greatly increased strains. With reference to the Clerk self-starter, *Fig. 30*, a great many of them had been made at Openshaw—many hundreds in the year—and it was found a very certain means of starting an engine. A slight error had been made by the Author with reference to Mr. Atkinson's first patent in gas-engines. He mentioned the fact that the first gas-engine was patented in 1880, but, as a matter of fact, he took the patent out in 1879 and constructed an engine. It was a very notable engine in some points. So far as he knew it was the first compression-engine ever made without a slide-valve, and it was also the first gas-engine ignited by means of a hot tube. It gave an impulse for each revolution, and it expanded the ignited charge to more than the original volume. Those were features to which the Author looked forward as being necessary features of gas-engines of the future. Mr. Atkinson.

Mr. F. W. Burstall wished only to criticise the cycle which the Author had adopted as his standard for the Crossley engine. Mr. Burstall.

Mr. Burstall. The particular expression he deduced was only true provided the specific heat of air was constant for all temperatures. Although the variation in the specific heat was not accurately known, it was certain that specific heat varied. In the Author's Paper in 1886 he quoted the experiments of Messrs. Mallard and Le Chatelier; but he refused to agree with the conclusions drawn from them, although he admitted that the experiments in themselves were perfectly accurate. Since that date the further experiment of Messrs. Sarreau and Vieille had been made on explosives, and from their conclusions Mr. Le Chatelier had drawn up a Table showing that the specific heat increased considerably with the temperature. The specific heat of a permanent gas increased from 1·0 to 1·3, between 0° C. and 1,000° C., taking the specific heat at 0° C. as 1·0, and that of carbon dioxide, which was one of the constituents of the exhaust product, increased from 1·0 to 1·6. These conclusions rendered all deductions of temperature in working out the diagrams of gas-engine calculations open at least to doubt. As to the direct measurement of temperature in the gas-engine cylinder, experiments had been made in the early part of 1895 with the Otto-Crossley Engine at King's College.[1] He exhibited the thermometer with which the temperatures were measured. The method was to measure the resistance of an extremely fine platinum wire, which was placed in the centre of the clearance space. The wire had a diameter of $\frac{1}{2000}$ inch, and its life was approximately 700 explosions of the engine. By far the greatest difficulty in work of that kind was to discover the form of thermometer which would stand at once a pressure of 200 lbs. per square inch, a temperature of certainly 1,200°, and at the same time retain its insulation. On the 16th March, 1895, with one thermometer at 10 per cent. of stroke, he obtained a temperature of 1,100° on the air scale. Another thermometer, with a wire of a different size, on 20th March, gave 1,140° at 10 per cent. At 20 per cent. on the first day it gave 1,045°, and on the second day 1,080°. The fluctuations, therefore, were by no means considerable, and all through the experiments the thermometer gave very closely the same result, even with wires which differed as much as 0·001 inch in diameter, which made a very large difference in their thermal capacity. A somewhat singular point occurred in one of the diagrams, that of 16th March, the temperature, instead of falling, uniformly remaining stationary between

[1] "The Measurement of Cyclically Varying Temperature," by Henry F. W. Burstall, M.A., *Philosophical Magazine*, vol. 40, p. 282, and Plates 1 and 2.

20 per cent. and 30 per cent. of the stroke. He was so doubtful about that point that he repeated the experiment a second time, and obtained the same result. At 20 per cent. the temperature was 1,045°, and in the second set 1,055°. At 30 per cent. in the first set it was 1,050°, and in the second 1,050°. He recalibrated the thermometer with great care afterwards, but could discover no error. In referring to the Author's Paper[1] on gaseous explosions, read before the Institution in 1886, in his experiments with coal-gas he had noticed the same point, which might be called point of recalescence, and alluded to it as a very singular phenomenon. During the experiments of 31st January he could find no trace of it, the only difference being that the temperature of the mains which were supplying the gas was excessively low during the time of the great frost, and the indicator cards showed very much smaller initial pressures. The experiments were being continued, and he hoped to have more information which was absolutely independent of the indicator. Mr. Burstall.

Prof. WILLIAM ROBINSON congratulated the Author upon having brought before the Institution a valuable Paper advocating the claims of compression. It was well known that the largely increased efficiency in internal-combustion engines was due in great part to increased compression. That point, however, should not be pressed too far, and he feared the Author had given it undue weight when compared with other practical conditions necessary for the satisfactory and economic everyday working of modern gas-engines. In 1862 Mr. Beau de Rochas had clearly given the chief conditions essential to efficiency, and pointed out the advantages of compression, small cooling surface and high piston-speed, in the four-stroke cycle of operations which he proposed to be followed in the gas-engine cylinder. The Beau de Rochas cycle was used fourteen years afterwards by Otto, who made his engine a success. Nevertheless, to Mr. Beau de Rochas was due the credit of laying down the sound basis of gas-engine theory, and his cycle should not be called the "Otto cycle" by the Author in the historical Table. Prof. Robinson.

The Paper was based on the fallacious assumption that the ideal efficiency of the air-engine, working under conditions that could not possibly obtain in practice, could be used to compare exactly the relative efficiencies of various gas-engines having different piston-speeds, and in which the cooling action of the walls was not the same. The expression given for the efficiency of the air-engine was correct, provided a number of conditions were fulfilled. He did

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 1.

Prof. Robinson. not, however, see how these could hold in practice, and the cycle of such an air-engine, in which there was neither gain nor loss of heat between the walls and the working fluid, could not be closely approximated to by that of actual gas-engines which are not equally affected by the loss to water-jacket, varying as it did between 30 per cent. and 40 per cent. of the total heat supplied; not to speak of the change in specific heats of gases at the high temperatures in the cylinder which vitiated theoretical calculations. It followed that the ratio of the actual to the ideal efficiency, calculated from compression alone, could not be rigorously compared, as in the Paper, with much advantage, whilst ignoring other factors which played important parts in producing the actual efficiency in gas-engines.

The great change in economy, from 16 per cent. in 1882 to 28 per cent. in 1895, had been attributed by the Author to increase in compression alone. That appeared incorrect, because the Author had himself stated in another part of the Paper that scavenging was absolutely essential to success with large gas-engines, especially when high compression was adopted. It was quite evident that scavenging must have a very important effect on the efficient working of gas-engines. He agreed with the remarks of Mr. Atkinson on the increase of economy due to sweeping the products of combustion out of the cylinder by pure air. The figures, given in the Paper, of the working of the Stockport and other engines, proved that much greater gain in economy than the 5 per cent. allowed by the Author, was due to scavenging. Again, it should be borne in mind that with large engines, such as were required for electric lighting, there were very great stresses produced in the cylinder by the high temperature of combustion and the want of uniformity in this heating action, and cooling by the water-jacket on the different parts of the cylinder. The frequency of the forces due to high compression, with the violent explosions, was very trying on the engine. The wear and tear must increase, and perhaps worst of all, the noise of the exhaust was sometimes seriously objectionable. For the cooling of the piston and valves, in order to obtain a uniform mean temperature throughout, the cylinder required careful design in large engines with high compression. In large engines there was a smaller amount of cooling surface when compared with the amount of gas present in the cylinder to generate heat. The gas did not conduct heat rapidly through itself to the cooling walls, and the surface of contact being comparatively smaller, relatively more heat was retained than

in small engines, and the high temperature was likely to fire the charge during the compression stroke. The result was a greater liability in large engines working at full power and using high compression without thorough scavenging, to pre-ignitions, back firing and unsatisfactory working. On the other hand, in some gas-engines, when running light and governing by partial cut-out, there was the trouble of slow-burning and incomplete combustion of the rejected mixture which was fired again in the exhaust pipe by the next discharged products, or ignited the new charge and caused back firing in the air-chamber. Prof. Robinson.

The scavenging arrangement of Messrs. Crossley and Atkinson relied upon the exhaust-pipe, about 65 feet long. It was not always convenient to lay such a great length of pipe, and the action must vary considerably with the number of bends, and the power at which the engine was working. In other words, supposing the engine was running light and cut off a charge altogether, would the back-pressure in the exhaust-pipe be the same as when the hot-burned products had escaped; and if not, what would happen when the exhaust-valve opened and when the admission took place on the next stroke? Would not some of the gases be likely to pass from the exhaust-pipe into the cylinder? Although an engine might give very economical results, running at full power and with regular explosions, if it had to run at half-load, light, at quarter-load, and so on, would not the results as to scavenging be different, depending on the temperature and pressure of the exhaust gases leaving the cylinder? Under varying conditions he feared the long pipe would not be found satisfactory. He was therefore inclined to advocate the claims of a positive scavenger such as in the Premier gas-engine made by Messrs. Wells Brothers, of Sandiacre, near Nottingham. In this engine a certain amount of fresh air was pumped through the cylinder, and effectually cooled the space about the valves. Better results could be obtained in this way and with certainty. In the "Premier" tandem engine of 100 HP. the air-pump piston was 1·8 times the area of the motor piston, and the power absorbed by the scavenging was only 1 per cent., much less than the loss due to back pressure in the Atkinson long-pipe arrangement.

The actual efficiency 0·228 of the Atkinson cycle-engine at the Society of Arts trials, as compared with its theoretical efficiency of 0·33, deduced by the Author from the volume of compression alone, proved this method of comparing actual and ideal efficiencies, as adopted throughout the Paper, to be inaccurate

Prof. Robinson. and misleading. The difference was attributed by the Author to extra expansion of gas. It was necessary, however, to point out that the formula (ii) used by the Author was not the proper expression for the theoretical efficiency in the Atkinson Cycle engine, even from the Author's standpoint. Moreover, the expansion even to original volume in the Cycle engine took place in about one-fourth the time occupied in an ordinary Otto engine, so that comparatively little time was allowed for the heat to pass to the cylinder walls, and, consequently, the high piston-speed during this explosion stroke gave rapid conversion of heat into work resulting in the high efficiency which Mr. Atkinson had obtained. No doubt the complete rejection of the products of combustion, ensuring a pure charge, and the rapid expansion, beyond the original volume of the charge, contributed to economy in the Atkinson Cycle engine.

A correction was made throughout the Paper, insisting on the latent heat of steam being included in the total heat of combustion of the charge. It was scarcely fair to the gas-engine to add the latent heat which was not developed as heat in the cylinder, and could not be made available without condensing the steam, which would be somewhat difficult in the cylinder of the gas-engine. Therefore he thought the latent heat ought to be deducted because it was carried away in the steam, and he agreed with the judges in doing so at the Society of Arts trials, as well as with Professor Thurston and Dr. Slaby, who were reasonably disposed towards gas-engines on this point.

With regard to the heat of combustion of gases used in the gas-engine, the Author had taken the heating values of coal-gas from the old analyses by Dr. Percy F. Frankland [1] made 1882 to 1884. The coal-gas used at the present day in London and several other large towns is very different from what was then used. Now ordinary lighting gas was very often enriched with oil-gas, and the composition obtained might not have the same heating power per cubic foot as coal-gas obtained directly from Cannel coal. In trials of gas-engines the heating value of the gas used could be very easily and directly determined by burning some of the gas in a Junker calorimeter, during the progress of the test, with a far greater degree of accuracy than by the old indirect, tedious and troublesome method of analysis and calculation. He had found the heating-power of Nottingham lighting-gas, and of Dowson gas, in this way, and could rely on the results given by the Junker

[1] Journal of the Chemical Society, No. cclix., 1884.

calorimeter to be correct within less than 0·5 per cent. A continuous test also could be made throughout the engine trial to show the variation, if any, in the quality of the gas-supply, at the same time avoiding the many sources of error in the calculation of the calorific value from the analysis. Prof. Robinson.

In the development of the gas-engine he looked forward to the general adoption of large engines, designed to use some kind of producer-gas, like Dowson gas or cheap fuel-gas; and, therefore, the ports and other parts had to be specially arranged to deal effectively with the charge of poor gas in large cylinders to ensure thorough mixing, certainty of ignition and complete combustion. These large engines were now made to be coupled directly to dynamos. He had recently taken diagrams of a "Premier" tandem engine made by Messrs. Wells Brothers, of Sandiacre, having a cylinder 15 inches in diameter, stroke 21 inches, air-piston 25 inches, and indicating 140 HP. at 180 revolutions per minute with Dowson gas. The continuation of the crank-shaft was the armature-shaft of the alternate-current dynamo, and the field-magnets acted also as fly-wheels. The pump diagram showed an expenditure of 1 per cent. of power in scavenging. The light-spring diagram gave 1·33 per cent. power lost in the suction- and exhaust-strokes, giving a total negative work of 2·33 per cent. The I.HP., running light to overcome this and the friction, was 12·3 per cent., giving B.HP. divided by total I.HP., equal 87·7 per cent. The frictional loss alone was about 10 per cent., and the engine ran very smoothly.

An important recent development was to be seen in the Acme gas-engine, made by the Acme Company, of Glasgow. The design was somewhat similar to a Willans steam-engine. The Acme was a high-speed vertical engine, having two single-acting cylinders working tandem on two-throw cranks, and coupled direct to the dynamo shaft. An independent six hours' test of an Acme gas-engine of 150 I.HP., running at 350 revolutions per minute, showed very slight variation of speed on the voltmeter, and the gas-consumption was at the rate of 15·9 cubic feet of Glasgow gas per I.HP. per hour. Two of these engines, of 150 I.HP. each, had been chosen by the Belfast Corporation to drive dynamos in the central lighting station.

Besides Dr. Otto, perhaps no man had done more than Mr. Atkinson to advance the gas-engine.[1] In fact, no one thing had

[1] See also "The Modern Development of the Gas-Engine," by James Atkinson, Manchester Association of Engineers, 10th November, 1894.

Prof. Robinson. tended so much to facilitate compression and satisfactory firing of charges as the method of hot-tube ignition. One of the first experimenters to use an iron tube heated on outside by flame had been Dr. Drake, in his early gas-engine. But Mr. Atkinson was the first to make a compression-gas engine in 1879, working with a hot-tube ignition almost identically the same as that in use at the present day. After the troubles of ignition by flame through a slide in compression gas-engines, the ease with which a highly compressed charge could be fired by a heated tube, which really made high compression possible could be appreciated.

As to the history of scavenging, he thought the first practical use of a scavenger arrangement was in the Linford engine of 1879, of the vertical type, the charge of gas and air being admitted between two pistons working simultaneously in opposite directions, the return stroke compressing the charge. The explosion took place between these two pistons, forcing one upwards and the other downwards, and the power was transmitted by rocking levers to the cranks, which, being in opposite directions, avoided all shock on the crank-shaft. On this account it was called the "Automatic" balanced gas-motor. A charge of air was passed through the cylinder and exhaust-pipe after each explosion. In 1879 this engine had been made in four sizes of 1 HP. to 5 HP. In 1885 the "Differential" engine of Mr. Atkinson marked a great advance in the development of gas-engines, and in 1886 this was superseded by his "Cycle" engine. But if the number of joints and moving parts in these engines told against them from a mechanical and commercial point of view, he failed to see the simplicity or advantage secured by the Author for his 1889 engine, which also had a good many joints. Its economy at continuous every-day work had not yet been proved.

Mr. Clerk. Mr. Clerk, in reply, said he was very much obliged to the members for their patience in listening to a somewhat lengthy and laborious Paper, and for the kind expressions used and the criticisms made on the different points. He need not say he was prepared to defend his position in all points. The $\theta\,\phi$ diagram had been referred to by Captain Sankey, by which he calculated the efficiency of the gas-engine from a different basis to that adopted in the Paper. Mr. Clerk had not studied the diagram, and could not speak as to its merits, but no doubt the formula afforded a very ready means of calculating efficiencies also. He had re-calculated the value, stated by Captain Sankey to be incorrect, and had found the same result. The figure, which referred

to the 73 per cent. efficiency of engines of 100 lbs. per square inch compression, 2,900° F. maximum temperature, was given in his book,[1] published ten years ago, and although some corrections had been pointed out, that particular figure had never been questioned, and was, as far as he understood, the correct value. With regard to the use of the Carnot cycle for gas-engines, it was the ultimate cycle which must be appealed to in deciding the absolute amount of heat which could be converted into work by any conceivable heat-engine. No engineer had ever thought it possible to follow Carnot and make an engine using the Carnot cycle in its entirety; but any gas-engine cycle, or even steam-engine cycle, was after all simply a mutilated Carnot cycle, by mutilating which in a certain way, any cycle for any type of gas-engine could be produced. He had made some calculations upon that point; an engine to carry out the Carnot cycle would weigh 20 tons perhaps and give 1 HP., which would be absurd. The Carnot cycle must always be appealed to, as Professor Beare had said, as showing the ultimate, not possible efficiency, but the ultimate ideal efficiency or the ultimate efficiency which was ideally possible. Different types of engines could only be compared by taking the absolute efficiency of the engine, not referring to the Carnot or any other cycle. The total number of heat-units given to the engine in the form of fuel, and the total number of heat-units accounted for by the indicator diagram, gave an absolute standard independent of all empirical considerations, which was necessary for the comparison of engines of different types. For instance, with a steam-engine, the Carnot cycle showed a certain limit of efficiency possible because the maximum temperature of the steam was known; but if it was stated that a steam-engine gave 80 per cent. efficiency, using the Carnot cycle as a standard, that indicated that the use of steam had only made it possible to realize a certain ideal amount, and 80 per cent. of that ideal amount was obtained. A gas-engine cycle differed from a steam-engine cycle in that, instead of having the temperature of steam in the boiler as the maximum limit, the temperature of the fuel in the furnace, that was to say, the gas mixture within the cylinder had the same relationship to the engine as the fuel in the steam-engine furnace,therefore, a very much longer range, which made it difficult to compare the relative efficiency of these two engines; the only practicable method was to take the total number of heat-units given to the two engines, calculate the ratio that represented

Mr. Clerk.

[1] "The Gas-Engine." London: Longmans, Green & Co., 1886.

Mr. Clerk. the Carnot scale, or any other scale, and then compare the two, which would give the absolute standard. In all the experiments and calculations of Dr. Slaby, Professor Thurston, and Dr. Kennedy, they adopted an arbitrary method of determining the heat of combustion of the gas, which was that, instead of taking the total heat evolved from atmospheric temperature back to atmospheric temperature, which was the real heat evolved by the combustion, whatever it came from, they only evolved down to 100° C., and that retained all the water in a state of vapour, and also heated the gaseous fluid to a certain extent. He did not think that was correct. It was quite right to do that, and so obtain a figure which gave a certain efficiency for the purposes of study, but he thought an absolute efficiency should be agreed upon, and that that should be on the lines he had indicated; and in determining that absolute efficiency, the whole heat generated, whether by condensed water or not, should be taken. With this heat of liquefied steam in some conceivable form of engine it was quite possible to obtain power; the function of the gas-engine then began where that of the steam-engine ended, and he thought it would be incorrect and misleading if the standard of combustion value which included all the heat evolved and not only a part of it was not used. The six-stroke cycle having alternate steam stroke had been tried and there were a good many inventions in which one stroke had been given by steam, but every one had proved a failure for one reason, which was quite sufficient, that if water was introduced into the interior of a gas-engine cylinder, many practical difficulties were at once met with. It interfered with the time of ignition in an entirely arbitrary manner, and anything likely to be gained in added force from steam evolved in the same cylinder was more likely to be lost in irregular and difficult ignition. The effect of introducing steam into the cylinder as making the ignition utterly uncontrollable had been shown very well by Mr. Chatterton, *Fig. 58*. To use the steam and gas-engine cycle, it was absolutely necessary to have a separate cylinder. No doubt a considerable efficiency could be added to the gas-engine by raising steam in the jacket and using it in a separate cylinder, but for small power engines that would be an absurd additional complication as long as there were other means open for improvement.

He would like to refer to Mr. Atkinson's remarks as to the economy realised by scavenging. He had always advocated scavenging, and he was not to be understood to say one word against it. He believed it was an excellent device. Perhaps the

Mr. Clerk.

Paper was somewhat misleading in stating that only 5 per cent. was to be credited to scavenging. What he meant was that only 5 per cent. was to be credited in engines operated by coal-gas. In using Dowson gas, where the gas-mixture was so weak that it was on the verge of missing ignition, a very small change in the relative amounts of the gas in an engine would make a large change of economy. In Dowson gas much more than 5 per cent. of benefit was obtained with scavenging, but with coal-gas that was not the case. In the experiment he had mentioned, if the indicated HP. and consumption of an Otto engine were taken, when running at full power, having therefore exhaust gases in the compression-space, and after having run a few strokes to take in air and gas free from exhaust gases, only a small percentage of economy would be found due to the presence of air, instead of exhaust gases. If the compression was increased it was another matter entirely, and different results might be obtained, but the results given could not be given except with Dowson gas. It should be noted, however, that in Mr. Dowson's remarks he appeared to confuse increased average pressure with increased efficiency. He was aware that the average available pressure could be greatly increased by scavenging, whether using Dowson gas or coal-gas, because more oxygen was present and more gas could therefore be burned. It was erroneous, however, to suppose that increased average pressure was necessarily accompanied by increased economy of gas-consumption. The average pressure in the cylinder could always be increased by scavenging; that was, an engine that was indicating only 9 HP., often could be made to indicate 12 HP. by scavenging, because more air was drawn into the cylinder so as to add more gas; but that was not increasing the economy. The results obtained by Mr. Atkinson were very interesting, but the indicated HP. alone should have been given; by giving the consumption of gas per brake HP., Mr. Atkinson somewhat confused the question by including the varying mechanical efficiency of the engine when using scavenging, as against the same engine with the lower mechanical efficiency when not using scavenging. The gas-consumption figures in Mr. Atkinson's various results without scavenging were higher than they ought to have been with Openshaw gas, for the powers of the engines tested. Thus in one experiment he had stated that he had obtained 36·53 B.HP. with 20·03 cubic feet of gas per B.HP., each without scavenging, while the engine with scavenging gave 39·91 B.HP., with a consumption of 16·9 cubic feet per

Mr. Clerk. B.HP. So large an engine with a compression of 80 lbs. per square inch and without scavenging should have given a much higher result than 20 cubic feet per B. HP. with 20 candle-power gas. The same remark applied to the other experiments quoted by Mr. Atkinson. This was the only explanation he could offer of the difference between Mr. Atkinson's results and his own. Greatly increased economy over an engine working without it could not be included among the advantages of scavenging. Without doubt engines having large port-spaces would be improved by scavenging without necessitating increased compression; but his own experiments with various types of engines showed that the economy of an engine with properly designed compression-spaces—that was compression-spaces having the minimum of port space and working with equal compression—would not be increased by more than about 5 per cent. by adopting scavenging. That the scavenging engine worked more nearly at the maximum strain for which it had been constructed was partly true. In the Crossley-Otto Scavenging Engine, as now made, however, the mixture was by no means the maximum possible explosive mixture for the amount of air present. It was therefore quite possible to have a heavy charge giving a much higher pressure of explosion than the ordinary working explosion. He agreed as to the other advantages of scavenging, and he trusted that he would not appear wanting in appreciation of Mr. Atkinson's invention when he differed with him upon what was a theoretical rather than a practical point.

He agreed with Mr. Bryan Donkin as to the importance of analysing the products of combustion from a gas-engine cylinder, and the necessity of making this analysis in all careful tests. His experience, however, showed that in properly constructed modern gas-engines the combustion of the gases was practically complete. In large engines, no doubt, at the moment the exhaust-valve was opened the flame still existed in the cylinder, and combustion was still proceeding. This defect could only be remedied by increased expansion or by some arrangement such as a compound engine which gave more time for combustion. Without doubt the thermal efficiency of the large engine was superior to that of the small engine.

It was truly remarked by Mr. Beaumont that increased speed of piston opened a method for increased economy not mentioned in the Paper. He had, however, given attention to this point both in

his previous Paper and elsewhere.[1] Further economies were to be gained by increased piston-speed, but it was to be borne in mind that the economy of an engine of given valve-dimensions might thereby be easily diminished. The port and valve areas in a high-speed engine required to be carefully designed to allow the cylinder to fill completely at the end of the stroke, and to allow the exhaust to discharge completely on the exhausting stroke. The ignition also had to be carefully arranged for high speed. Loss in weight of the charge or displacement of the explosion line at once reduced the economy. In small engines high piston-speeds were not practicable for many reasons such as those he had indicated. The shape of the explosion space and configuration of the ports was undoubtedly important, but there was now little probability of engineers going astray with the many successful engines at present before them. In other cycles, however, than the Otto, the difficulties were not yet overcome, and although he was still firmly of opinion that better cycles than the Otto would be found, he did not wish to under-rate its good points, or the difficulties still to be met. Mr. Clerk.

He agreed with Professor Hudson Beare's remarks, but he hardly thought it necessary to warn engineers that the consumption rate given by an engine in ordinary work at less than maximum power were greater than the consumptions mentioned in the Paper. This fact was well known to all engineers dealing with either gas- or steam-engines. He was aware that the gas-engine was still inefficient from a thermodynamic point of view, but notwithstanding this inefficiency it gave a greater conversion of heat into mechanical work than any other known motor.

He was interested in the remarks of Mr. Burstall, who, however, appeared to be under some misapprehension as to the nature of the standard used in calculating gas-engine efficiencies. Assuming the change of specific heat of air to be as stated by Messrs. Berthollet and Mallard and Le Chatelier (with which he did not agree) the air cycles and the formulas used in the Paper would not be affected. The standard would be as valuable whether the specific heat of air changed or not. "The direct measurement of the temperature in a gas-engine cylinder by an electric resistance thermometer," was referred to by Mr. Burstall, who appeared unaware that the present method of determining the temperature of the gases in the gas-engine cylinder was necessarily more

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 220, and "The Gas Engine," pp. 144, 145, 172, 175.

Mr. Clerk. accurate than any resistance thermometer could be. The present method consisted in using the gases in the cylinder to form a gas- or air-thermometer, and the average temperatures were certainly known in the gas-engine cylinder with a close approximation to accuracy—much closer than was possible with resistance thermometers, all of which were graduated above experimental temperatures of calibration by the system of prolonging the curve obtained between certain temperatures, and no standard temperatures of anything like 2,900° F. (ordinary gas-engine temperature) were known as a means of correcting or calibrating such thermometers. It appeared preferable to rely upon the air-thermometer—that was the pressure change within the cylinder itself—to obtain the temperature, than to rely upon any indirect method such as the resistance thermometer. He had observed the point of recalescence referred to by Mr. Burstall in his experiments communicated to the Institution in 1886,[1] but it was obvious only where the gas was rich in ethylene, or other dense hydro-carbons.

He agreed with Prof. Robinson's remarks as to certain advantages to be gained by a positive scavenger such as was used in the Premier Gas-Engine. Such positive scavenging he had long advocated, and, indeed, applied to an impulse-every-revolution engine as early as 1881. The question of the proper standard of heat value was not one of favourable consideration or otherwise to the gas-engine, but was one of a correct standard from an absolute heat-engine point of view, and on this point he considered the only true method of regarding the question was the one adopted by himself. He could well have filled a paper with gas-engine detail, but engineers interested in those motors did not require to be informed on ordinary matters of detail, and it was therefore necessary to deal with the question from a broader standpoint.

In conclusion he thanked the President for his kind expressions with regard to the Paper, and stated it was a great pleasure to him to bring before the Institution a Paper on a subject to which he had now given some twenty years' consideration.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 15.

Correspondence.

Mr. Llewelyn B. Atkinson observed that, in addition to the figures given in the Paper relating to the consumption of coal-gas, corresponding data for producer gas, upon which the future of the gas-engine as a prime mover so largely depended, would be of interest. Whilst in his earlier Paper [1] the Author had emphasized the great importance of engines of the second class in his classification, those igniting at constant pressure without explosion, they were in the present Paper passed by with the remark that they "may be regarded as having disappeared from the field," the expectations in relation to them not having been realized. It would add greatly to the value of the Paper to supplement it by some detailed explanation of the failure of this class of engine. When it was realized that in engines of large power, say 300 HP. and upwards, for marine and other purposes, the Otto-cycle engine was impossible, this subject appeared of the greatest importance. In the late Prof. Fleeming Jenkin's lecture [2] on gas- and caloric-engines it was very clearly set forth why the Otto cycle gave mechanically a higher efficiency. But the fact that the regenerator might be used with the constant-pressure cycle and not in the Otto cycle, appeared a reason why the latter might be made to equal the former in total efficiency, whilst the possibility of stopping and starting such engines, the smaller fly-wheel necessary, the more moderate and maintained pressure in the cylinder, all pointed to the great practical advantage of this cycle. Intermediate between this cycle and the Otto cycle was the engine alluded to in the same lecture by Prof. Jenkin, where the gases, after compression, passed through a regenerator, doing work at constant pressure before being ignited. This cycle which in theory showed considerable advantages, had not been dealt with at all by the Author, but in the improvement of the gas-engine would probably occupy a highly important place. Mr. L. B. Atkinson.

Mr. R. J. Durley considered the progress during recent years in the economical working of the gas-engine was no doubt largely due to the causes the Author assigned. He seemed, however, to have somewhat lost sight of the large amount of heat running to waste in the jacket-water, in the diminution of which a considerable Mr. Durley.

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 220.

[2] "Heat in its Mechanical Application," Inst. C.E. Lectures, 1883-84, p. 101.

Mr. Durley. further improvement in the performance of the gas-engine might probably be obtained. This waste in many gas-engine trials approached and often exceeded the loss due to heat carried away by the exhaust gases. In Prof. Capper's trial of a 7-HP. Crossley-Otto engine at King's College, London, 6,340 foot-lbs. were expended per explosion, while 10,825 foot-lbs. and 11,245 foot-lbs. respectively were carried off as waste by the jacket water and exhaust. The actual efficiency was thus $\frac{6,345}{27,820} = 0{\cdot}228$, the number of explosions per minute being seventy-four. If it were possible to increase the number of explosions to, say, 100 per minute, while retaining the same exhaust-temperature, and therefore the same exhaust loss per explosion, the time during which the heat of each explosion was given to the jacket would be reduced in the ratio of 100 : 74; and, assuming the rate of transmission through the cylinder wall to remain unchanged, it might be taken that the heat given to the jacket would be $\frac{10,825 \times 74}{100}$ or 8,010 foot-lbs. per explosion. The $(10,825 - 8,010) = 2,815$ foot-lbs. thus saved would appear as useful work, and the efficiency would rise to $\frac{6,345 + 2,815}{27,820} = \frac{9,160}{27,820} = 0{\cdot}329$. To obtain the same exhaust-temperature as before, expansion would have to be carried further, and, as pointed out by the Author, this might render compound working advisable. It seemed plain, however, that an increase in the number of reciprocations per minute would tend to economy. The scavenger action introduced in the new Crossley engine would no doubt be found of value in preventing back ignition and other difficulties likely to arise when working at higher speeds than were now usual. He desired to ask in what form such difficulties were likely to present themselves, and how far such a mode of diminishing the jacket loss would be effectual.

Mr. Foster. Mr. Herbert F. Foster, of Westminster, thought that information as to governing gas-engines, and also as to their excessive weight, power for power, when compared with the steam-engine would be of interest. These were the weakest points of all the present forms of gas-engines, that governed by the "hit-and-miss" method when working at low loads, as it necessitated a large storage of power in the fly-wheel to overcome the irregularity of the impulses, and also considerable increase in the mass and weight of its moving parts. The gas-engine was a crude and inefficient machine in this respect when compared with a steam-engine of the same size, especially when working at low powers; and it would not successfully

compete with its rival steam in its more important uses unless this difficulty was overcome and the constant mixture and variable compression method were used for governing, instead of by missing explosions. This might be effected, particularly in engines for large powers, by increasing the speed and relieving the piston head of the sudden shock of the explosion by an air-buffer. The air-buffer permitted a much higher degree of compression to be used without throwing the great and sudden stresses due to the high initial effect of the explosion on the working parts, which consequently required to be of massive design. The pressures in the working cylinder at the moment of the explosion, owing to the volumes varying inversely as the pressures in the air-cushion, would be somewhat more than one-half of the usual effect when working in the ordinary manner; whilst the mean pressure, and therefore the power developed by the engine, would be greatly increased. He considered the explosion-every-revolution engine had a great future; but that the abolition of the Otto method of working was not therefore necessary, as most engines giving an impulse every revolution were compelled to use a separate cylinder and pump. Two Otto cycles, therefore, one lagging 360° behind the other and placed in tandem, realized the same result with less complication. He had devised such an engine, in which a displacer air-cushion piston acted between the two main pistons coupled in tandem so as to form alternately the combustion-chambers of the two cylinders. The required conditions of a scavenging-engine were thus fulfilled, the displacer-piston alternately filling the combustion-chamber spaces and expelling all the burnt products in a mechanical manner, and at the same time allowing a higher degree of expansion to be used, as the volume of the cylinder was greater during the explosion stroke than when inhaling the new charge. In the development of the gas-engine, especially in its application to railways and to ships, as the Author had suggested, it should be borne in mind that the engines would have to start and reverse, in an equally easy manner, as in the case of steam-engines. The problem was of great difficulty, and, in the case of the latter engine, almost a century had been required for its solution to bring it to its present state of perfection; but it was to be hoped that in the gas-engine the problem would sooner yield to the investigation of the many workers on the subject.

Mr. Foster.

Mr. J. H. Hamilton, of Sandiacre, was particularly interested in the remarkable result the Author had obtained in a test of a Crossley-Atkinson scavenging engine, as he had long realized the advan-

Mr. Hamilton.

Mr. Hamilton. tages offered by a pure and cool combustible charge. The greater specific heats of carbonic acid and steam at high temperatures would indicate that the less of these constituents the exhaust contained, the less heat would be lost in it.[1] Another advantage of scavenging lay in the increased theoretical efficiency possible, without raising the maximum temperature, by lowering t in the formula $\frac{T - t}{T}$. The relative loss of heat to the wall was also less for dense mixtures. It was well known that the power and economy of a gas-engine diminished if the charge was heated before admission. The mechanical efficiency would be greater with the high mean pressures that were obtained from a rich and cool charge. That the increase of the economy of the gas-engine, as made by Messrs. Crossley, was due alone to higher compression was refuted by the Author's own figures. By an increase in compression from 60 lbs. to 90 lbs. per square inch, the Stockport engine gained 7·5 per cent., while an increase of compression from 61 lbs. to 87·5 lbs. per square inch, combined with scavenging, resulted in the 4-HP. engine tested by the Author realizing higher efficiency than the 9-HP. Crossley engine at the Society of Arts by 28·4 per cent. Though these engines were not exactly the same in other respects, it would be absurd to attribute any considerable portion of this gain to minor improvements. The advantage of scavenging was most apparent at high compressions, but it was not negligible at low compression, and the Author made a double error in stating that three-cycle engines "did not show any large increase in economy due to the pure charge." In the first place they had not a pure charge, for about one-third of the contents of the combustion-chamber after the scavenger-stroke had taken place was filled with products of combustion; and in the second place, a three-cycle engine, when as well-proportioned as a Crossley-Otto of the same period, showed a considerable advantage.

In the year 1888, in which the Author tested a 9-HP. Crossley engine, Dr. Kennedy tested a 4-HP. Beck engine, of the three-cycle type. The engines were strictly comparable as to constructive details, both having slides. The compression was also practically the same in both, but in other respects the Crossley engine had the advantage. Its cylinder was 2 inches larger in diameter, and the stroke was 3 inches greater, and yet the gas consumption of the Beck was 20·67 cubic feet per I.HP. against 23·98 cubic

[1] "Recherches Expérimentales et Théoriques sur la Combustion des Mélanges Gazeux Explosifs," by Messrs. Mallard and Le Chatelier, pp. 251–258.

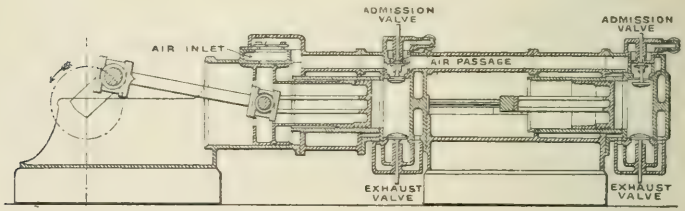
feet for the Crossley. The gas was of about the same quality in both tests. That is to say, the three-cycle engine showed an economy 16 per cent. greater than the Crossley, or about twice as much as that due to increased compression in the case of the Stockport engine cited by the Author. If the increase in efficiency from 0·16 to 0·28 was due to compression alone, as stated by the Author, how did he explain the fact that many of these long-pipe scavenger engines, when running under the less favourable conditions of ordinary work, failed entirely to approach the figures obtained in special tests? It was probably because, owing to the sensitiveness of this arrangement to slight alterations in the working conditions, the scavenging action did not take place. The compression remained constant, and therefore the economy could not be due entirely to it. The greatest gain from scavenging seemed to be placed by the Author at 5 per cent. on the consumption of a Crossley engine running light, as compared with a loaded one, but such an experiment was untrustworthy for two or three reasons. In many engines the gas-valve was some distance away from the admission-valve, and thus at every cut-out there was a waste of gas, which would diffuse into the passing air, and be carried into the exhaust with it. The ignition also, if well timed for the full load, would not be so well timed for the light load, and this would likewise cause loss of power. In addition, the most suitable amount of gas would be different for a pure mixture, and for one containing products of combustion. Mr. Hamilton.

In 1890 he had sought to apply the scavenging system to the four-stroke type of engine, as obviously the six-stroke engine had a great disadvantage so far as power and regularity of running were concerned, and was, moreover, not a perfect scavenging-engine. An engine constructed to his design by Messrs. Wells Brothers had been exhibited at the Crystal Palace Electrical Exhibition in the year 1891–2. It had a differential piston which acted as an air-pump. The air was drawn through light valves into the annular space in front of the motor-cylinder and was compressed into a large clearance-space by the backward movement of the piston. The capacity of the clearance-space was such that the pressure increased about 4 lbs. per square inch above atmospheric pressure, and on the explosion-stroke this air simply re-expanded; but on the exhaust-stroke the admission-valve was opened about half-stroke, and the air, having been then compressed to about 2 lbs. per square inch above atmospheric pressure, began to flow into the combustion-chamber, displacing the products

Mr. Hamilton. of combustion during the remainder of the stroke, while the piston paused on the centre. The exhaust-valve was held open until the crank had well passed the centre, and the gas-valve opened as soon as the exhaust closed. The valve-setting was identical with that afterwards adopted by Messrs. Crossley and Atkinson, described by the Author on page 111, except that the air-valve was opened a little earlier. In this engine the compression was 65 lbs. per square inch, and the gas-consumption 16·7 cubic feet per I.HP. hour.

The most recent development of this type of scavenging engine was the tandem engine, of which a section was given in *Fig. 63.* Several of these engines had been constructed, the largest indicating about 140 HP. with Dowson gas. In this engine the air was forced alternately through the combustion-chambers of the two motor-cylinders, so that there was a discharge at each back-stroke after the large air-piston had passed the air-ports. The side-rods

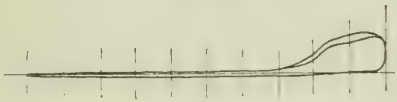
Fig. 63.



connecting the two pistons were attached to this large air-piston, and it also acted as a guide for taking the lateral thrust of the connecting-rod. The power absorbed in forcing the air through the combustion-chambers was shown by the pump-card, *Fig. 64*, and in *Fig. 65* was shown a card from one of the motor-cylinders when working with Dowson gas. The vertical scale of the former was fifteen times that of the latter; but as the effective areas of the pump and motor-pistons were as 1·8 to 1, the equivalent mean pressure on the motor-pistons was obtained by multiplying that shown by the card by 1·8. The I.HP. of the pump was thus 1·5 in 134—that was, 1·12 per cent. of the total I.HP. This low ratio was obtained by providing ample passages and large valve-area. These tandem engines were specially suited for high compressions, because in them the mass of the moving parts was considerable, and their inertia helped to equalise the pressure on the crank-pin. The dotted line in *Fig. 65* showed the effect of the inertia of the moving parts on the pressures, the ordinates between

it and the atmospheric line representing the horizontal compo- Mr. Hamilton.
nents of the pressure on the crank-pin at corresponding points on the stroke. As there was compression at each returning stroke, and as this was almost always in excess of the inertia, there was no reversal of pressure, and the brasses could be run slack without knocking. A 60-HP. engine of this type, with 67 lbs. per square inch compression, used 15·6 cubic feet of Nottingham gas per I.HP. hour.

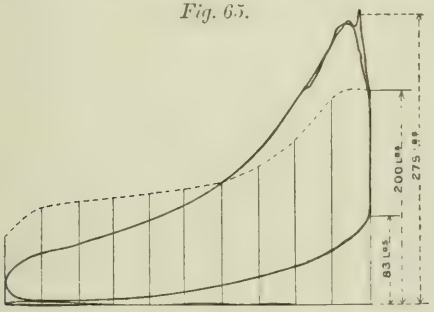
Fig. 64.



Scale, $\frac{1}{12}$th.

With such an engine, all the advantages which the Author claimed for the two-stroke type built by him in 1887, such as increased expansion, &c., could be obtained in a simpler manner; and it was indeed surprising that, with all his experience of two-stroke engines, the Author should advocate their use for large powers, for whatever success they might have when built in moderate powers, failure would be almost certain when the greatly enhanced difficulties accompanying larger sizes came to be met.

Fig. 65.



Scale, $\frac{1}{100}$th.

As the Author acknowledged, one of the great difficulties with large engines of the Otto type arose from excessive heat, though the cylinder was only exposed to it during one-fourth of the cycle. This difficulty would be much greater in an engine having double the number of explosions and only one-third of the interval between them. It was during this interval in the Otto engine that the walls cooled by conduction. Again, the Author pointed out the loss of power in his 1887 engine when

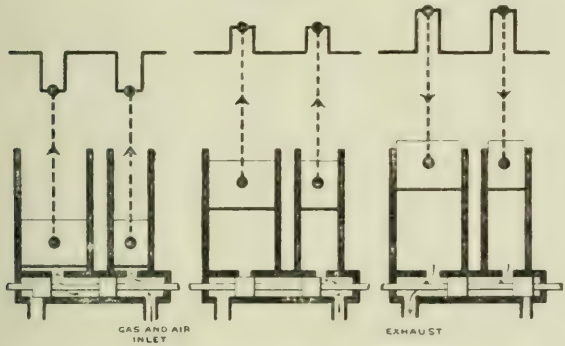
Mr. Hamilton. the ignition was slow—a loss that would be expected when the speed of the piston at the igniting-point was considered. Large engines would now have to use producer- or fuel-gas, which, it was well known, was less prompt and less certain in ignition than coal-gas; and even in engines as now made, in which the piston remained at rest, or moved very slowly while ignition took place, it was difficult to avoid late firing; but if the piston were moving fast, while the compression was also decreasing at the moment of the opening of the ignition-valve, as in the Author's design, misfires would be very frequent. Other features of the engine would condemn it, such as the complicated method of governing, the necessity for compressing to a higher degree, and the greater risk of back ignitions.

In discussing the further possible gain from increasing compression, the Author mentioned the known property of suppression of heat; but its amount was not known at high compressions, and it was unscientific to assume that laws which held true for mixtures ignited at atmospheric pressure would hold true for very much higher pressures. If the phenomenon was due to slow combustion or dissociation, it was unlikely that the relative amount of heat suppressed would be so great at the higher pressures as it was at the lower, and even if due to increase of specific heat or incipient dissociation, it did not follow that the ratio would be the same. Therefore he considered the Author's figure for the possible efficiency too low.

Mr. Humphrey. Mr. H. A. Humphrey remarked that from the Paper it was easy to summarize the principal good qualities which a highly economical gas-engine must possess. They were (*a*) simplicity of construction; (*b*) high compression; (*c*) scavenging out of burnt products; (*d*) small port surface; and (*e*) expansion to lower pressure than usual. Other things being equal, the impulse-every-revolution engine had an advantage over the Otto type, and for very large powers the compound principle was advisable. One of the latest attempts to combine these points was illustrated in *Figs. 66*, which showed the principle of a new impulse-every-revolution engine he had devised, the principal feature of which was that the clearance space of both the pump and the motor-cylinder was movable, and acted first for one and then for the other. The explosive mixture from the pump was compressed into an auxiliary cylinder between a pair of pistons rigidly connected together, so that the space between them constituted the clearance or compression volume. When the pump had completed its in-stroke, the pair of pistons moved in the auxiliary cylinder until their motion was just about to bring the

space between them into communication with the motor-cylinder. Mr. Humphrey.
The compressed mixture was then exploded, and the products of combustion entered the motor-cylinder for the working stroke. The pair of pistons also performed all the functions of the ordinary valves, which were consequently dispensed with. A third piston was added to the left of the exhaust-port for large engines, in order that the pressure of the exhaust-gas might be balanced. This was an important matter, because considerable difficulty had been experienced in working ordinary exhaust-valves of large area, the wear on the cams being excessive. It had been found necessary in Otto engines to provide a small additional exhaust-valve, to open a little in advance of the large valve, in order to relieve the pressure before operating the latter. The distributing-pistons of the engine had, therefore, no tendency to move under the action

Figs. 66.



of the explosion or from the pressure of the exhaust-gas, and they were easily cooled by internal circulation of water through the hollow valve-rod which held them together and passed out at both ends of the auxiliary cylinder. Their motion was derived from link-work driven directly from an eccentric on the main shaft, and was such that the ports were opened and closed rapidly while the motion was slow between them. No bevel wheels were required. A small additional clearance in the motor-cylinder itself enabled a portion of the exhaust products to be compressed before communication was established with the auxiliary cylinder, and these products absorbed some of the heat from the high temperature charge as it entered. This did not reduce the temperature, because combustion was not complete at the time. The auxiliary cylinder was the only one which required scavenging, and this was accomplished by withdrawing it from communication with the motor-

Mr. Humphrey. cylinder before expansion was complete, and when the pressure was about 35 lbs. per square inch. Two valves were provided, and by opening first one leading to the long exhaust-pipe, and then one leading into the air, the well-known suction effect, which Messrs. Crossley and Atkinson had made such good use of, cleared out the auxiliary cylinder. There was, however, a great difference between this action and the ordinary Otto cycle scavenging charge which swept out the motor-cylinder. In the suction-stroke of the pump gas and air were first drawn in, and then air only; consequently no gas was left between the right-hand distributing-piston and the end of the auxiliary cylinder. This was necessary because, if the governor shut off the gas-supply at the next stroke, no waste of gas occurred. If no explosion took place, the motor-piston would tend to create a vacuum after expanding the charge of air back again to the pump volume; but this was prevented by a valve opening inwards, placed at the proper point in the motor-cylinder, and uncovered by the motor-piston. It was entirely automatic.

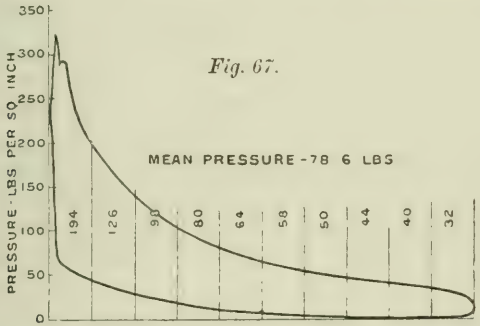
When ordinary engines were made of very large size, the great shock which occurred at the moment of explosion was serious; but in the new engine it was entirely taken by the distributing-pistons, between which the explosions occurred, and there was no possibility of its being communicated to the bed-plate. It was easy to make the engine compound by the addition of another cylinder and an extra distributing-piston to govern its port. The compound engine gave two impulses every revolution, having half a revolution between them, and so the turning-moment could be made as steady as in a steam-engine. The theory of the engine admitted of the greatest economy, and its special features rendered it suitable for very high powers.

Mr. Hunt. Mr. Charles Hunt observed that in 1880 Messrs. Crossley had supplied him with two Otto gas-engines, each of 12 HP. nominal, with cylinders 11½ inches in diameter, and 16 inches stroke. In the following year he had made a series of trials for the purpose of ascertaining the consumption required of gas of various qualities, from 12 candle-power to 29 candle-power.[1] It appeared from his tests that in the comparison of results obtained in different localities insufficient attention was paid to the quality of the gas used. His results did not confirm the reference of the Author to the results obtained with Glasgow gas by the Philosophical Society of Glasgow, viz., 22 cubic feet per I.HP. per hour, as the lowest con-

[1] Transactions of the Gas Institute, 1882, p. 202.

sumption of gas recorded at that time. They showed, on the contrary, with 26-candle gas, which was at that time the quality of Glasgow gas, a consumption of only 16·26 cubic feet per I.HP. per hour. Stress had been rightly laid by the Author upon increase of compression as the main source of improved efficiency and economy. The value of compression was proved by his own experience, which showed at the same time how greatly the working of old engines might be improved by comparatively simple means. Taking advantage of the need for repairs, he, at the suggestion of a member of his staff, had applied to one of the engines already mentioned a new liner and piston, by which the pressure of compression is increased from 30 lbs. to 62 lbs. per square inch. No provision was made for scavenging. The diagram, *Fig. 67*, showed the results obtained, the gas-consumption, Mr. Hunt.

Fig. 67.



Diameter of cylinder, 11¼ inches; stroke, 16 inches; speed, 159 revs. per min.; B.HP., 17·4; I.HP., 19·8; maximum pressure of explosion, 320 lbs. per sq. inch.

18·3 cubic feet per brake HP., being lower than the best examples quoted by the Author, taking into account the quality of the gas used, Openshaw gas being 20 candle-power, and Birmingham gas 17 candle-power, according to which the engine at Openshaw ought only to have required less than 16 cubic feet per brake HP. per hour instead of 17 cubic feet, which was the recorded consumption. The first Lanchester self-starter had been applied to one of these engines, and was still working satisfactorily. Ignition-tubes had long since taken the place of the original slide-valves in both engines.

Mr. C. F. Jenkin asked if the Author would give the exact data by which he had calculated the "heating value of gas" from its analysis. In a Paper on the "Efficiencies of Gas-Producers"[1] he had shown that very different values have been stated for the Mr. Jenkin.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. Appendix iii, p. 346.

Mr. Jenkin. heating powers of the different gases by various authorities, so for purposes of comparison it was of considerable importance to know which values the Author had used.

Mr. Pinkney. Mr. C. W. PINKNEY, of Smethwick, had, since 1878, experimented with several types of scavenging and non-scavenging engines, as well as with engines in which the cooling of the exhaust-gases in a predetermined length of exhaust-pipe, and the vacuum formed therein was used not only for scavenging, but also for recharging the cylinder with gas and air. An engine built in Birmingham in 1886 was referred to by the Author and illustrated in Fig. 38, Plate 5. The experiments had been conducted and several of the engines made at Messrs. Tangyes' works, but they had not proved successful. The mechanical difficulties were such that the most skilful handling could not keep the engines at work; the settings were also of such a delicate nature that the slightest inaccuracy caused terrific back firing. After careful study of this engine he disagreed from the Author as to the economy of large engines of this type; and as to the practicability of the engine illustrated in Fig. 44, Plate 5. The mechanical difficulties were such as to preclude its use in the most skilled hands.

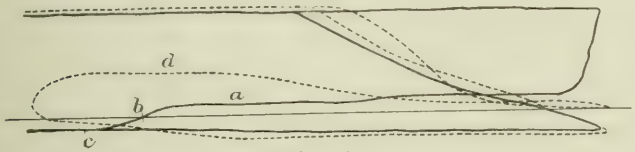
In 1881 he had experimented with Mr. James Robson on a scavenger engine, in which the vacuum formed in the exhaust-pipes, &c., served to draw air through the self-acting valve for clearing out the exhaust-gases while the exhaust-valve remained open. He had, in 1888, designed an engine constructed so as to clear the exhaust-gases out of the cylinder and give an impulse each revolution; this engine, several examples of which were now working, had given good results, and had only been withdrawn in view of the great demand for the Otto-cycle engine constructed by Messrs. Tangye.

The scavenger engine of Messrs. Crossley and Atkinson was alluded to in the Paper as a decided advance in the modern engine. Several of these engines were in operation, a few of which he had had the privilege of testing, the sizes varying between 4 HP. and 14 HP. In no instance had he been able to realize the results given by the Author and Mr. Atkinson, not even at the maximum load; but when running light and without load, he had found a great increase in the consumption of gas, which indicated an increase in all the intermediate loads. This no doubt was due to the length of exhaust-pipe required, which considerably increased the back pressure on the exhausting stroke, when the governor prevented ignition, as shown by the dotted line, *Fig. 68*. In some instances considerable back pressure was registered.

Mr. Pinkney.

In an ordinary or non-scavenging engine, if the exhaust-pipe must be excessively long, the area could be increased to prevent back pressure; but not so with the exhaust-pipe of the scavenger engine, or the time of causing the vacuum would be altered and useless for the valve-settings of the engine. Scavenging was desirable, but he doubted whether the method set forth by Messrs. Crossley and Atkinson was either reliable, effective, or economical; and if the Author was correct in stating that only 5 per cent. could be credited to scavenging with coal-gas at full load, it was useless, as a gas-engine was not installed to work at full load; and if it worked at say three-fourths full power, the 5 per cent. gain would at once be converted into a serious loss on the score of scavenging. The diagram, *Fig. 68*, taken from a 14-HP. Tangye engine, showed clearly, according to settings indicated in *Fig. 15*, that a large amount of the air blocked in the exhaust-pipe when the engine was missing ignitions or governing, as shown by dotted line *d*, again entered the cylinder, as the exhaust-valve did not close until

Fig. 68.



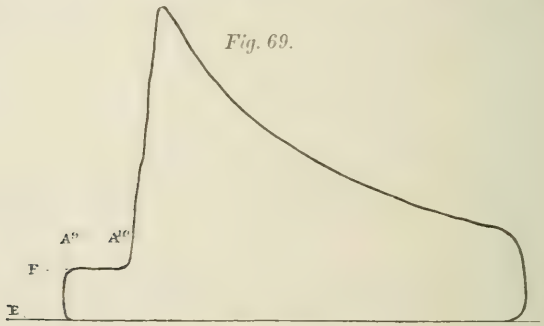
Scale, $\frac{1}{4}$th.

the crank had travelled say 45° on the charging stroke. The exhaust line, *a*, crossed the atmospheric line at *b*, and fell to *c* when the engine was firing. This tended to somewhat weaken the mixture and spoilt the first ignition after cut-out, and was mainly responsible for the large consumption of gas when the engine was working on light or intermediate loads. He agreed with the Author as to compression and knew it led to fuel economy, but there were many difficulties to overcome, such as shock, excessive heating of internal working parts, lubrication, and proper distribution of metal to overcome uneven expansion, which scavenging, as it was now known, did not overcome. There were many large gas-engines working with the compression-space 34 per cent. of the volume swept by the piston, which did not give the results set forth in *Fig. 2*, and the form of combustion-chamber was such as to expose less cooling surface than that shown in *Fig. 14*.

At the River Wear Commissioners No. 1 dock, there were in all three direct-coupled gas-engines and centrifugal pumps, one of 8 HP. for driving the leakage pump, air-exhausting pump, and

Mr. Pinkney. the starting pump, and two 40 HP. driving the centrifugal pumps. At first it had been proposed to drive the centrifugal pumps by means of belts, but at the suggestion of Mr. H. H. Wake, the Commissioners' engineer, it had been decided to couple the gas-engine crank-shaft direct to the centrifugal-pump spindle. To successfully start such large engines, Messrs. Tangye had fitted one of their most powerful starters, which started the engines and pumps with rapidity and ease. This starter, which he had devised, was most powerful, the gearing, igniter, &c., being specially arranged to put the engine and load into motion before allowing ignition to take place. The average pressure was in many instances more than 100 lbs. per square inch. The crank of the engine was put into the most suitable position, the pressure of gas and air being stored in a reservoir by the aid of a pump, and the ignition-valve was held on to its seating by a suitable lever and cam; when the

Fig. 69.



Scale, $\frac{1}{12}$th.

pressure was let into the cylinder from the reservoir, the pressure increased from E to F, *Fig. 69;* the engine would then creep from A^9 to A^{10}, at which position the ignition-valve was opened and ignition took place which put the engine rapidly into motion. One man started the engine in a few minutes. This starter has often started large engines against full load.

A large tandem engine, built by Messrs. Andrews of Reddish, was referred to by the Author and shown in Fig. 23, Plate 5, but no mention was made as to its successful working or economy. The largest successful single-cylinder engine in this country, viz., 24 inches by 30 inches, had been made by Messrs. Tangye and set to work at Messrs. McLaren's Works, Glasgow. It was capable of giving a maximum of 170 I.HP. and 144 B.HP., and consumed about 0·75 lb. of Scotch anthracite per HP. per hour (cost of coal 12*s.*

per ton, which was much inferior in quality to Welsh anthracite), and this consumption was obtained when the engine was running at its constant working load, viz., 100 B.HP. Mr. Pinkney.

Dr. Du Riche Preller considered that for the direct propulsion of tram-cars or trains, gas-engines could not successfully compete with electricity, nor even with compressed air or steam, for they involved too many complications. A motor which, like the gas-motor, had to be kept running constantly, even when the vehicle which carried it stood still, was necessarily a very uneconomical machine. On the other hand, he had great faith in the future of gas-engines for power-stations of electric tramways and railways. From the results obtained in an installation of this kind with which he had been concerned, he thought that, next to hydraulic power, there was nothing so simple, clean, and economical as an electric tramway power-station where gas-engines of the Crossley or a similar type, with separate starting apparatus and working on the Otto cycle and consuming Dowson or other producer-gas, were used. As compared with steam-generating plant, the first cost of such installations was about the same; but in working, the gas-plant showed a saving of between 40 per cent. and 50 per cent. in fuel alone, and the attendance for gas-generating plant, gas-engines and dynamos was reduced to two men, which ensured a further saving of about 10*s.* per day. The one defect of gas-engines for traction installations was their inability to stand the sudden overloads which constantly occurred in such work, where an automatically registered load-curve showed a succession of maxima to minima and *vice versâ*, often in the space of one minute. This disadvantage was in most installations of that kind overcome by a storage battery coupled in parallel with the dynamos, so that the fluctuations were compensated, and the gas-engines could run at constant speed and load. It was often said that large fly-wheels, such as were usually fitted to gas-engines, should suffice to balance sudden variations of load, and that hence the expense of a storage battery, which amounted to at least £1,500, could be saved. In a recent test the storage battery had been disconnected and the gas-engine left to bear alone the fluctuations of load, with the result that at the first or second overload it stopped dead in spite of the fly-wheels. Dr. Preller.

Mr. G. Richard, of Paris, could not adopt the view expressed by the Author that the stratification theories had been definitively condemned, as it had been demonstrated that in many gas-engines, notably in those in which the mixture of gas and air was admitted behind the burnt gases and by the same passage as the ignition, Mr. Richard.

Mr. Richard. the changes taking place were in conformity with those laid down by Dr. Otto's theory. It had been proved by Prof. Dewar, Prof. Dwelshauvers, Dr. Slaby and other experimenters, that at the moment of ignition, and after compression, the cylinder contained a mixture of air, active gas and burnt gas, of heterogeneous composition, richest in the neighbourhood of the ignition port. It might be that, in some high-speed engines, in which certain simple precautions, indicated by Otto to favour the natural tendency of the gases not to mix uniformly, were not observed, this heterogeneity was not so distinct as in the engines used by those experimenters, but this proved nothing adverse to the views which Otto had expressed. The evil caused by the partial preservation of the burnt gases, as it was practised in the Otto engine, was at least too small to justify the various complications which had been introduced to expel them. On the other hand, the presence of the burnt gases did not impede the complete combustion of the active gas, and it appeared to diminish rather than augment the losses through the cylinder-walls and the exhaust. The slightly higher economy obtained from some engines giving complete scavenging of the burnt gases could be attributed in great measure to the increase of speed and compression, as was probably the case in the Crossley-Atkinson engine. In any case, the 30 per cent. economy stated to be effected by the expulsion of the gas was far from being realized.

The preservation of the burnt gases had historically played a foremost part. All the inventors of gas-engines prior to Otto, from Lebon, in 1801, the inventor of compression, to Beau de Rochas, had admitted as *a priori* indispensable, the complete expulsion of the burnt gases, the presence of which would have inevitably occasioned imperfect combustion and back ignitions. Accordingly, many complications had been introduced to completely expel the gases, and the realization of the practical compression-engine had thus been retarded for seventy years. The discovery, by Otto, of partly preserving the burnt gases without impairing the certainty of the action or diminishing the efficiency of the engine constituted a radical simplification, from which the modern engine had sprung. As the Author had said, the most important factor in the economy of gas-engines was compression, the influence of which was easy to explain theoretically. On the hypothesis of completely isothermic expansion, and of an increase of pressure of explosion, p, proportional to the compression, c, the ratio, ρ, of the work produced by the combustion of a certain volume of gas with compression, c, to that produced without compression

was given by the formula $\rho = 1 + m \log c$, in which, the mixture being constant, $m = \frac{p-1}{p \log p}$, p being the pressure of explosion. This formula, established on the most favourable hypothesis for compression, showed clearly that its advantage, increasing with the logarithm of c, augmented less quickly than proportionally to the compression. Thus, in passing from a compression of 2 atmospheres to one of 3 atmospheres, the gain would be 19 per cent.; and in passing from nine atmospheres to eleven atmospheres it would be only 5 per cent. Mr. Richard.

In practice, as the Author had also well remarked, the effects of compression were much more complex, because they were influenced by several secondary actions, notably by that of the cylinder walls and the speed of the engines, pointed out by Dr. Slaby, from which they could not be isolated. The primary effects of compression had been recognized by all the designers of engines since the time of Otto. Its amount was not limited until the point of spontaneous ignition was reached; but, besides economy, the questions of durability, cost, and repairs of the engine should be considered. The adoption of high compressions and speeds had been impeded, not by ignorance of the advantages which attended them, nor by the impossibility of realizing a convenient ignition, for electric ignition had long been known, but by the difficulties of construction to practically realize these compressions and speeds. Analogous difficulties had been encountered in ammonia and carbonic acid refrigerating-machines, but they had been gradually overcome.

The question of compound gas-engines certainly deserved to be taken up in the sense indicated by the Author. It would be interesting to know the results of the trials made by Messrs. Hartley, Dick, and Kerr, as well as by the Author and Mr. Lanchester, with their new compound engine of 1894, constructed to work at explosion pressures of 40 atmospheres in the small cylinder. As to slow-combustion or constant-pressure engines, they did not appear to have been definitively condemned, as the Author thought, at least for large powers, because it was possible to give great sweetness of action to such engines, of which the theoretical efficiency was almost equivalent to that of engines exploding under constant volume. Engines of exceptionally high powers had scarcely fulfilled the hopes which had been raised by the publication of their trials. To obtain the great sweetness of action in slow-combustion engines, poor mixtures must be employed, giving a combustion-temperature sufficiently low not to

Mr. Richard. lose too much heat by the cylinder walls. The Gasmotoren-Fabrik of Deutz had recently experimented with a motor of this kind, in which the ignition was, despite the small total power of the driving charge, perfectly assured by very simple methods. Engines of this type lent themselves much more readily than others to the use of regenerators, of which the theoretical economy was undeniable.

The tube ignition was that now most in favour, its principal advantage being its great power, assuring, in well-designed engines, a sufficiently rapid and complete combustion, even at high speeds. Electric ignition, however, presented the advantage of being always ready without previous heating, and of easy duplication, permitting instantaneous replacement. This was an important consideration, especially in engines driving public electric-lighting services where the electricity necessary for ignition is always at hand. In engines of high powers, the exhaust-valves heated considerably, and the pressure of the gas rendered their rapid opening difficult to operate without shock. It was necessary to cool them by an independent circulation of water in their boxes, accompanied by a light sprinkling on the valves. If it could not be avoided the action could at least be deprived of shock by partly balancing the valves, as Mr. Dawson had indicated, under the pressure of the exhaust. In some engines, the regulation was effected by varying the point of ignition with the speed and the richness of the mixture by advancing the ignition as the mixture was more feeble and the natural point of ignition later. This had been perfectly brought out by the experiments of Davies, and this mode of regulation had been put in practice, notably by Mr. Krupp. It would also be interesting to ascertain the economic advantage, probably sensible in the case of engines of very variable powers, of governing by complete closure of the motor-cylinder, the cooling of the empty passages and of the cylinder being thus diminished.

Mr. Stevenson. Mr. G. E. Stevenson considered the Author's statement, that "the gases thus expand after explosion, doing work on the piston, and the expansion terminates when the gases have attained the volume which they occupied in the same cylinder before compression commenced," incorrect, for the volume of gases was increased by the combustion, and the temperature to which the products of combustion were raised, and therefore the expansion, would not terminate until after the gases had been released from the cylinder, and occupied a larger space than that which they occupied in the cylinder before compression. At the commencement of the exhaust-stroke there still remained a very considerable

pressure at the back of the piston, which was very distinctly shown in *Figs. 17* and *18*, pp. 111 and 112. In some engines this pressure amounted to 40 lbs. per square inch. Mr. Stevenson.

Whilst recognising that economy resulted from the "scavenging" process, the Author failed to set forth clearly how this economy was effected. The advantages of this improvement, in completely expelling the spent gases and ensuring that the succeeding charge should be a mixture of gas with pure air, were more particularly manifest when an engine was working with a full load than with a light one. In the latter condition of working, the omission of several explosions might have the effect of completely clearing out the spent products in a non-scavenging engine, through the action of successive exhaust-strokes. When this occurred, the next charge would be of full explosive strength, but, so soon as a heavier load was applied, the power of the engine became diminished by the vitiation of the charges, when working strokes succeeded each other without omission. It had been stated by the Author that he was unable to credit the scavenging process with more than 5 per cent. of economy, and he had laid stress upon the economy effected by increase of compression. Two trials had been instanced of a Stockport engine, in one of which the engine worked at 60 lbs., and in the other at 90 lbs. per square inch compression, the economy resulting from the increased compression being 7 per cent. (19 cubic feet − 17·6 cubic feet = $\frac{1{\cdot}4 \text{ cubic foot}}{19}$ = 0·07 cubic foot) of the gas consumed at the lower rate of compression. The efficiency was given as 0·208 for the first and 0·225 for the second trial, or an increase of 8 per cent. When, however, the Author tested a 4-HP. Crossley "scavenging" engine he had obtained an efficiency of 0·250, and when testing a 14-HP. "scavenging" engine he had obtained an efficiency of 0·275. It would appear, therefore, that the smaller Crossley engine showed an efficiency 11 per cent. greater, and the larger Crossley engine 22 per cent. greater, than the Stockport engine working with 90 lbs. per square inch compression. It seemed reasonable to suppose that, in view of these facts, the Author had understated the economy obtainable from the "scavenging" process. Referring to the exhaust-pipe required for the scavenging engine, the Author had given 65 feet as the length necessary to sufficiently delay the production of the vacuum, causing a suction, until the piston had arrived at the end of the exhaust-stroke. It did not appear clear why such delay should be necessary, for the sooner the pressure at the back of the piston was relieved after the crank had passed the

Mr. Stevenson. dead centre the better, and when once the spent gases were discharged and followed by a draught of pure air, they could not re-enter the cylinder.

Scavenging engines were, however, fixed by Messrs. Crossley with much shorter exhaust-pipes than the Author recommended. Two 10-HP. engines at the Manchester gasworks had exhaust-pipes 3 inches in diameter, and about 30 feet long, a length which Messrs. Crossley regarded as sufficient for the purpose. In dealing with engines other than on the Otto principle, the Author emphasized the desirability of an impulse-every-revolution cycle for large engines. He made little reference, however, to the attempts which had been made to increase the recurrence of impulses by duplicating the Otto cycle. This duplication might be effected either by using two cylinders and setting the cycles to work alternately, or by making the engine double-acting. In duplicating the cycle by the use of two cylinders, these had been arranged either as pair cylinders working on cranks at 180°, or as tandem cylinders working on the same crank, and finally, as face to face cylinders working on the same crank. Double-acting engines had also been made, in which the front end, as well as the back end, of the cylinder was utilized for motive-power. The principal difficulty with such engines appeared to lie in the overheating of the piston-rod and stuffing-box, due to the explosion in the front end of the cylinder. It might also be said that an economy in the cost of a gas-engine, due to the greater frequency of impulses, could hardly be realized, for an increase of dead weight would be essential to the life of such an engine, in order that it might safely withstand the more rapidly recurring shocks of the explosions, and the greater strain of the power exerted.

Dr. A. Witz. Dr. A. Witz, of Lille, agreed with the Author in attributing to the great increase in the initial compression the remarkable economies now realized in gas-engines. The generic theory established by Dr. Witz in 1883 indicated the increase of economy resulting from a high compression; the experimental theory showed besides that the losses by the cylinder-walls ought to diminish when the exploding mixture was confined in a more reduced space at the moment of ignition. The difficulty lay in realizing these indications of theory. The inventor of the Simplex engine had been the first to succeed, as the trials[1] he had made in November, 1885, at Rouen, showed a consumption of 562 litres

[1] "Traité théorique et pratique des Moteurs à gaz et à petrole," par A. Witz, troisième edition, tome i, page 213; Paris, 1891.

per I.HP. per hour, at 0° Cent. and 760 millimetres pressure, of gas containing 5,460 calories per cubic metre. The construction of engines had since followed in the same direction, and greater and greater compressions had been rendered possible, until further progress was stopped by the premature ignition of the charge. This difficulty had, in some cases, been overcome by more effective cooling of the combustion-chamber, and in others, notably in the Crossley-Atkinson engines, by scavenging the products of combustion by a current of air. The advantage of this scavenging appeared indirect, especially since it had been demonstrated by Mr. Frederick Grover that higher pressures were recorded when residual gases took the place of an excess of air, and that the time of an explosion was much reduced when excess of air was replaced by the products of combustion.[1] The success formerly obtained by Schrab, who recarburated the burnt gases and introduced them again in the cycle, further confirmed this view. The good results obtained by Messrs. Crossley were incontestible, their cause, however, was still a matter for discussion. He looked forward to the opportunity of making tests upon these scavenging engines, but he questioned whether the success would be the same in engines of all powers, and what would be their speed, the limit of their governing-power, and the temperature of their cylinder-walls, which he regarded as the most important questions. Scarcely better results could be obtained than those recorded by Messrs. Crossley and Atkinson, but perhaps they could be realized as well by other means. From the theoretical point of view this diversity among the solutions of the problem was of paramount importance. Dr. A. Witz.

Mr. Clerk, in reply to the Correspondence, was pleased to find, from the observations of Mr. L. B. Atkinson, that there were still engineers who took an interest in engines outside of the Otto cycle. The disappearance of the constant-pressure engine was due to the fact that its development had been arrested by the great financial success of the Otto cycle. So much had been learnt with regard to explosion and combustion, by the aid of the Otto engine, that he considered engineers were now in a better position than ever to produce engines of the constant-pressure type. He by no means despaired of this type of engine, which would have a field in the future, especially for large engines. Mr. Clerk.

In reply to Mr. Durley, high speeds would undoubtedly increase economy by diminishing the time of the loss of heat, but there

[1] "The Effects of the Products of Combustion upon Explosive Mixtures," by F. Grover, *The Practical Engineer*, Manchester, 1895.

Mr. Clerk. were many strange facts which became apparent when experiments were made to increase economy in that manner. He had always considered the existing methods of governing gas-engines crude and ineffective. An engine, however, by Messrs. Fielding and Platt on the Otto cycle, had succeeded in giving an impulse at every second revolution under all conditions of load. The economy at light loads was less than the economy at great loads, but, within wide limits, little loss occurred. He could not agree with Mr. Foster as to the use of the air-buffer in the engine cylinder. Air-pistons had been long tried, and had always been found troublesome and ineffective. Nor could he agree with Mr. Hamilton that Dr. Kennedy's test of the 4-HP. Beck engine could be fairly compared with his 1888 test of the 9-HP. Crossley engine. The Beck engine was a special one carefully prepared for trial, whilst the Crossley engine was an ordinary one tried without change in adjustment, or any attempt to secure an abnormal economy. There was nothing which could be credited to the scavenging in the Beck engine in a consumption of 20·67 cubic feet I.HP. Such consumptions had been previously noted. He was aware of the difficulties in making the experiments he had mentioned, and all precautions were taken to eliminate possible sources of loss of gas. At the same time he admitted that scavenging produced good results, and allowed of higher pressures of compression being utilized. So many other conditions affected the economy of a gas-engine, that it was not safe to hurriedly adopt the conclusion that increased economy was due to any one change of operation. He could not agree with Mr. Hamilton as to the merits of two-cycle engines. He was delighted, however, to find that Mr. Hamilton considered his forecast of probable efficiency to be too low, and not too high. He quite agreed that further experiments were required on compressed gaseous mixtures. The results of Mr. Humphrey's trials of his new engine would be learned with interest. It appeared as though Mr. Hunt had omitted to consider that 26-candle gas, as manufactured by him, was probably of much higher heating value than the 26-candle gas used in Glasgow. Surely it was preferable to take the direct results of experimenting with gas in Glasgow than results obtained in Birmingham with the experimental gas supposed to be of the same composition as the Glasgow gas. In reply to Mr. Jenkin, the values used in calculating the heating value of gas from its analysis had been given in his 1882 Paper.[1]

Gas-engines, as at present constructed, were comparatively

[1] Minutes of Proceedings Inst. C.E., vol. lxix, p. 220.

unsuitable for the direct propulsion of cars or trains, but the difficulties to which he alluded were kept well in mind by gas-engine designers, and would, doubtless, be eventually overcome. He considered Mr. Richard's statement as to the continued existence of stratification theories to be incorrect. In reply to Mr. Stevenson, the statement in the Paper as to the expansion of gases had been accepted in every definition of gas-engine cycles published since his 1882 Paper. The difficulty involved in comparing two different gas-engines did not appear to be sufficiently appreciated by Mr. Stevenson, otherwise he would not so readily believe that he fully understood the cause of the difference of efficiency in the two engines to which he referred. The gas used by the Stockport engine was assumed by Mr. Stevenson to be the same as that used by the Crossley engine; but that assumption was incorrect. He could only state that at present the result of all his experiments so conducted that the only change in the same engine was the difference that in one case where scavenging was used, and in the other where it was not used, resulted in an economy of only about 5 per cent. Indirectly, no doubt scavenging did cause greater economies than this by permitting higher compressions without fear of premature ignitions. He was pleased to find himself in agreement with so eminent an authority as Dr. Witz, who had studied both the scientific and the experimental theories. With regard to Mr. Grover's experiments mentioned by Dr. Witz, he had examined the account of these experiments, and he considered that they by no means established the point that higher pressures were obtained with residual gases than without them. No doubt in Mr. Grover's experiments such was the case, but his experiments were conducted under conditions which did not secure the proper admixture of gas and air. This was clearly shown by the maximum pressures obtained by him, which were invariably lower than those obtained in Mr. Clerk's experiments. Under these conditions many curious results might be obtained, which had no bearing whatever on gas-engine questions.

Mr. Clerk.

4 February, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

MONTGOMERY PENROSE COODE.
JOSEPH JONES GARDINER.
GEORGE GREGORY.
RICHARD HACK.
ROBERT ABBOTT HADFIELD.
HENRY WILLIAM HARGRAVE.
HENRY ASHTON HILL.
HENRY LEONARD HINNELL.
CHARLES HARLOWE LOWE.
MUNCHERJEE COWASJEE MURZBAN, *Khán Bahádur*, C.I.E.
ALFRED CORNELIUS NEWCOMBE.
WILLIAM WEEKS SZLUMPER.
ALEXANDER JAMES WILLIAM WATKINS.
CHARLES JAMES KNIGHT WATSON.

And that the following Candidates had been admitted as

Students.

WILFRID HOCART BISHOP.
JAMES THOMAS HAROLD BURRELL.
ARTHUR CAMERON.
WILLIAM JAMES DAVIES.
ROBERT DAVISON.
LOUIS CHARLES JOHN DOXAT.
FRANCIS PIERRE DU SAUTOY, B.A.
WILLIAM FORGAN.
ROBERT ANDERSON GRAY, B.Sc.
BENJAMIN WRIGHTSON HEAD.
BARNARD HUMPHREY.
DANIEL HARRISON MACDONELL.
ROBERT CARRINGTON MIDDLETON.
GEORGE FREDERIC PALMER.
EGBERT WYON SMITH.

The Candidates balloted for and duly elected were: as

Members.

THOMAS HENRY BAILEY.
JAMES DREDGE.
HARDMAN ARTHUR EARLE.
GEORGE HAY.
ROBERT SAMUEL LLOYD.
WILLIAM HENRY MAW.
EMILIO ARMANDO HENRIQUE SCHNOOR.
WILLIAM SHIPP.
JAMES REW SHOPLAND.
JOHN JAMES WARBRICK.

Associate Members.

Andrew Barton.
Walter Bassett Basset.
Charles Thomas Broxup.
Edwin Codling, B.Sc., Wh.Sc.
Thomas Brammall Cooper, B.Sc., Stud. Inst. C.E.
John James Cowley.
Gilbert Joseph Dawbarn, B.Sc.
Stanley Dunkerley, M.Sc.
George Noble Fell.
Francis Joseph Harvey.
John George Heslop, Stud. Inst. C.E.
Edward Charles Hodge, Stud. Inst. C.E.
Edwin Hulme, Stud. Inst. C.E.
Arthur William Ker.
Thomas Lawrence Lewis.
George Rankin Love.
Malcolm Macpherson.
John Henry Medlicott.
Harry Powell Miles.
William Muirhead.
Ernest John Oakley, Stud. Inst. C.E.
John Gabriel O'Sullivan.
Hugh Pierce, B.A.
William Edwin Pincombe, Stud. Inst. C.E.
Ernest William Proctor-Sims.
Frederick Stanley Ransome.
David John Reid.
Thomas Pearson Robson.
Alfred John Saise.
Charles Edward Schenk.
Christopher Robert Ind Scott.
Joseph Slater, Stud. Inst C.E.
Ferdinand Augustus von Sobbe, Stud. Inst. C.E.
Charles Stamp, Stud. Inst. C.E.
George Gerald Stoney.
James Warry Vickers.
William Douglas Walker.
Frank Adamson West.
Alfred Arthur Williamson.
Henry Woodall.

The discussion upon the Paper "Recent Developments in Gas-Engines," by Mr. Dugald Clerk, Assoc. M. Inst. C.E., was continued and concluded.

SPECIAL GENERAL MEETING.

6 February, 1896.

Sir BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The following notice convening the meeting was taken as read:—

28 *January*, 1896.

Notice is hereby given that a Special General Meeting of the Corporate Members of The Institution of Civil Engineers will be held at 25, Great George Street, Westminster, on Thursday, the 6th day of February, 1896, at half-past four o'clock, for the purpose of considering a Supplemental Charter to enable the number of the Members of the Council of the Institution to be increased, and the votes of Members not actually present at a Meeting to be taken into account in the election of the President, Vice-Presidents and Members of the Council of the Institution; and, if approved of, directing the presentation of a Petition to Her Most Gracious Majesty, praying Her to grant to the Institution the said Royal Charter.

JAMES FORREST,
Secretary.

The following are copies of the Draft Supplemental Charter and of the Petition referred to:—

Victoria, by the Grace of God, of the United Kingdom of Great Britain and Ireland, Queen, Defender of the Faith.

To all to whom these presents shall come greeting—

Whereas the body politic and corporate of The Institution of Civil Engineers was incorporated under or by virtue of a certain Charter or Letters Patent, bearing date at Westminster the 3rd day of June, in the ninth year of the reign of King George the Fourth and the said Institution is now regulated and governed by and according to the provisions of the said Charter or Letters Patent, and a certain Supplemental Charter or Letters Patent, dated the 3rd day of August in the fifty-first year of our reign, and by or according to certain By-laws and regulations made by the said Institution. And whereas by the said Charter or Letters Patent of the ninth year of the reign of King George the Fourth it is provided (*inter alia*) that there shall be a General Meeting of the Members of the said body politic and corporate to be held from time to time as therein mentioned, and that there shall always be a Council to direct and manage the concerns of the said body politic and corporate, and that

the General Meetings and the Council shall have the entire direction and management of the same in the manner and subject to the regulations therein mentioned, and that at all General Meetings and Meetings of the Council the majority of the Members present and having the right to vote thereat respectively shall decide upon the matters propounded at such Meetings, the person presiding therein having, in case of an equality of numbers, a second or casting vote. And that the Council shall consist of a President, four Vice-Presidents, and not more than fifteen nor less than seven other Members, to be elected out of the said body politic and corporate, and that it shall be lawful for the said body politic and corporate to hold General Meetings once in the year or oftener, for the purposes therein mentioned, including (*inter alia*) that the General Meeting shall choose the President, Vice-Presidents, and other Members of the Council, and that the General Meetings shall make and establish such By-laws as they shall deem to be useful and necessary for the regulation of the said body politic and corporate and (*inter alia*) for fixing and determining the manner of electing the President, Vice-Presidents, and other Members of the Council. And whereas the said recited portions of the Charter of the ninth year of the reign of King George the Fourth were unaffected by the said Supplemental Charter of the fifty-first year of our reign, and still remain in force. And whereas the said Institution presented their humble petition to Us alleging (*inter alia*) as follows:—

"At the time the said Charter of the ninth year of the reign of King George the Fourth was granted, the number of Members of all classes was 156, the prescribed number of the Council was sufficient to enable the Institution to place upon the Council an adequate number of representative men having regard to the total number of Members, and the scope of all branches of Engineering science as then taught and practised throughout the Realm; and the number of Members residing in or near to the Metropolis formed a large proportion of the whole number, and could reasonably be expected personally to attend General Meetings for the purpose of electing a President, Vice-Presidents, and other Members of the Council."

"On the 2nd day of January, 1896, the number of Members of all classes was 5,969; the prescribed number of Members of the Council is no longer sufficient to enable the Institution to place on the Council an adequate number of representative men having regard to the total number of Members, and the scope of all branches of Engineering science, as now taught and practised throughout the Realm; and the number of Members residing in or near the Metropolis now forms a comparatively small portion of the whole number, and a large proportion cannot now be reasonably expected personally to attend General Meetings for the purpose of electing a President, Vice-Presidents, and other Members of Council. It is desired by the Members of the Institution and it is expedient, that the maximum number of Members of the Council (exclusive of the President and Vice-Presidents) should no longer be limited to 15, but should be such number as may be from time to time fixed by the By-laws, having regard to the growth and requirements of the Institution, and that in the maximum number there may be included such number (not being more than four) of Past-Presidents of the Institution, to be appointed by the Council from time to time in accordance with By-laws to be made in that behalf, to act as Members of the Council together with the President, Vice-Presidents, and elected Members of the Council; and that the minimum number of Members of the Council (exclusive of the President and Vice-Presidents

but inclusive of any Past-Presidents appointed as aforesaid) should be raised from 7 to 22; and that the power of taking part in the election of a President, Vice-Presidents, and elected Members of Council should not be confined to Members actually present at a general Meeting; and that the Institution should have power to conduct such election by means of ballot or voting papers in such manner as may be from time to time prescribed by By-laws made in accordance with the said Charters."

Therefore the Petitioners most humbly supplicated Us to grant Our Royal Charter for the purpose of enabling the number of Members of the Council of the Institution to be enlarged in manner aforesaid, and for the purpose of enabling the votes of Members not actually present at a Meeting to be taken into account in the election of the President, Vice-Presidents, and other Members of the Council of the Institution.

Now know ye that We taking the premises into Our Royal consideration, of Our especial Grace, certain knowledge and mere motion have granted, constituted, and appointed, and by these presents, for Us, Our heirs and successors, do grant, constitute and appoint in manner following, that is to say:—

That notwithstanding anything in the Charter of the ninth year of the reign of King George the Fourth, incorporating The Institution of Civil Engineers, the By-laws of the Institution may from time to time prescribe a maximum number of Members of the Council (other than and exclusive of the President and Vice-Presidents) and that from and after the enactment of any such By-law the number of Members of the Council (other than and exclusive of the President and Vice-Presidents) shall not be more than the maximum so prescribed, nor less than 22.

That, notwithstanding anything in the said Charter, the By-laws of the Institution may from time to time prescribe that a certain number (not being more than four of the Members of the Council) shall be former Presidents of the Institution, to be appointed by the Council from time to time, in accordance with such By-laws, to act as Members of Council together with the President, Vice-Presidents, and elected Members of the Council, and so that the Past-Presidents so appointed shall, while they hold office under such appointment, be deemed to be Members of the Council for the purpose of computing the maximum and minimum number of Members, and for all other purposes.

That, notwithstanding anything in the said Charter, the votes of Members not actually present at Meetings at which the election of the President, Vice-Presidents, and other Members of the Council (other than Past-Presidents appointed under this our Charter) is propounded, or at which the President, Vice-Presidents, and Members (other than as last aforesaid) are chosen, may be taken into account by means of ballot or voting papers or instruments of proxy as may be prescribed by By-laws from time to time framed for that purpose by the Institution.

That the Council, consisting of a President, four Vice-Presidents and not more than the maximum number for the being prescribed by the By-laws, nor less than twenty-two other Members constituted in accordance with this our Charter, shall have the direction and management of the concerns of the said body politic and corporate,

and the rights and duties conferred on the Council elected out of the said body politic and corporate in accordance with the said Charter of the ninth year of the reign of King George the Fourth.

And we do hereby, for Us, our heirs and successors, grant and declare that these our Letters Patent, or the enrolment or exemplification thereof, shall be in all things valid and effectual in law according to the true intent and meaning of the same, and shall be construed and adjudged in the most favourable and beneficial sense for the best advantage of the said Institution, as well in our courts as elsewhere, notwithstanding any recital, misrecital, uncertainty or imperfection in these our Letters Patent.

In witness whereof We have caused these Our Letters to be made Patent. Witness ourself at Westminster the day of in the 59th year of our reign.

By Warrant under the Queen's Sign Manual.

To the

QUEEN'S MOST EXCELLENT MAJESTY IN COUNCIL.

The Humble Petition of The Institution of Civil Engineers, of which Sir Benjamin Baker K.C.M.G., LL.D., F.R.S., is the President; John Wolfe Barry Esquire C.B., F.R.S., William Henry Preece Esquire C.B., F.R.S., Sir Douglas Fox, and James Mansergh Esquire are the Vice-Presidents; William Anderson Esquire C.B., D.C.L., F.R.S., Alexander Richardson Binnie Esquire, William Robert Galbraith Esquire, James Henry Greathead Esquire, John Clarke Hawkshaw Esquire M.A., Charles Hawksley Esquire, John Hopkinson Junior Esquire M.A., D.Sc., Wh.Sc., F.R.S., Alexander Blackie William Kennedy Esquire LL.D., F.R.S., Sir Guilford Molesworth K.C.I.E., Captain Sir Andrew Noble K.C.B., F.R.S., late R.A., Sir Edward James Reed K.C.B., F.R.S., William Shelford Esquire, Francis William Webb Esquire, Sir William Henry White K.C.B., LL.D., F.R.S., and Sir Edward Leader Williams are the Members of the Council; and Sir John Fowler Bart., K.C.M.G., LL.D., Sir Charles Hutton Gregory K.C.M.G., George Robert Stephenson, Esquire, William Henry Barlow Esquire F.R.S., James Abernethy Esquire, F.R.S.E., Lord Armstrong C.B., LL.D., D.C.L., F.R.S., Sir Frederick Joseph Bramwell Bart., D.C.L., F.R.S., Edward Woods Esquire, Sir George Barclay Bruce, Harrison Hayter Esquire, and Sir Robert Rawlinson K.C.B., are Past-Presidents:

Humbly sheweth as follows:—

The Institution of Civil Engineers was incorporated under or by virtue of a certain Charter or Letters Patent, bearing date at Westminster the 3rd day of June, in the ninth year of the reign of King George the Fourth, and the said Institution is now regulated and governed by and according to the provisions of the said Charter or Letters Patent, and a certain Supplemental Charter or Letters Patent, dated the 3rd day of August in the fifty-first year of Your Majesty's reign, and by or according to certain by-laws and regulations made by the said Institution.

By the said Charter or Letters Patent of the ninth year of the reign of King George the Fourth, it is provided (*inter alia*):—

> That there shall be a General Meeting of the Members of the said Institution to be held from time to time as therein mentioned, and that there shall always be a Council to direct and manage the concerns of the said Institution, and that the General Meetings and the Council shall have the entire direction and management of the same in the manner and subject to the regulations therein mentioned, and that at all General Meetings and Meetings of the Council the majority of the Members present and having the right to vote thereat respectively shall decide upon the matters propounded at such Meetings, the person presiding therein having, in case of an equality of numbers, a second or casting vote;
>
> That the Council shall consist of a President, four Vice-Presidents, and not more than fifteen nor less than seven other Members, to be elected out of the Members for the time being of the said Institution, and that it shall be lawful for the said Members to hold General Meetings once in the year or oftener, for the purposes therein mentioned, including (*inter alia*) that the General Meeting shall choose the President, Vice-Presidents, and other Members of the Council, and that the General Meetings shall make and establish such by-laws as they shall deem to be useful and necessary for the regulation of the said Institution and (*inter alia*) for fixing and determining the manner of electing the President, Vice-Presidents, and other Members of the Council.

The said provisions were unaffected by the said Supplemental Charter, and still remain in force.

At the time the said Charter of the ninth year of the reign of King George the Fourth was granted, the number of Members of all classes was 156, and the prescribed number of the Council was sufficient to enable the Institution to place upon the Council an adequate number of representative men having regard to the total number of Members, and the scope of all branches of Engineering science, as then taught and practised throughout the Realm; and the number of Members residing in or near to the Metropolis formed a large proportion of the whole number, and could reasonably be expected personally to attend General Meetings for the purpose of electing a President, Vice-Presidents, and Members of the Council.

On the 2nd day of January, 1896, the number of Members of all classes was 5,969, and the prescribed number of Members of the Council is no longer sufficient to enable the Institution to place on the Council an adequate number of representative men having regard to the total number of Members, and to the scope of all branches of Engineering science, as now taught and practised throughout the Realm; the number of Members residing in or near the Metropolis now also forms a comparatively small portion of the whole number, and a large proportion cannot be reasonably expected, personally, to attend General Meetings for the purpose of electing a President, Vice-Presidents, and Members of Council.

It is therefore desired by the Members of the Institution, that the maximum number of Members of the Council (exclusive of the President and Vice-Presidents) should no longer be limited to fifteen, but should be such number as may be from time to time fixed by the by-laws, having regard to the growth and requirements of the Institution, and that in the maximum number there may be

included such number (not being more than four), as may be fixed by by-laws from time to time, of Past-Presidents of the Institution to be appointed by the Council from time to time in accordance with by-laws to be made in that behalf, to act as Members of the Council together with the President, Vice-Presidents, and elected Members of the Council; and that the minimum number of Members of the Council (exclusive of the President and Vice-Presidents, but inclusive of any Past-Presidents appointed as aforesaid) should be raised from seven to twenty-two; and that the power of taking part in the election of a President, Vice-Presidents, and elected Members of Council should not be confined to Members actually present at a General Meeting; and that the Institution should have power to conduct such election by means of ballot or voting papers in such manner as may be from time to time prescribed by by-laws made in accordance with the Charters of the Institution.

> Your Petitioners therefore most humbly supplicate Your Majesty to grant your Royal Charter to enable the number of Members of the Council of the Institution to be enlarged in manner aforesaid, and to enable the votes of Members not actually present at the meetings to be taken into account in the election of the President, Vice-Presidents, and Members of the Council of the Institution.

The PRESIDENT having explained the objects which the Council had in view in recommending a Petition to the Crown for a Supplemental Charter, concluded by moving:—

> "That the proposed Supplemental Charter and the Petition to Her Most Gracious Majesty be, and are, hereby approved; and that the President be authorized to seal the Petition for presentation accordingly."

The motion was seconded by Sir DOUGLAS FOX, Vice-President.

Sir GEORGE BRUCE, Past-President, moved as an amendment:—

> "That a meeting be held this day fortnight, to confirm or otherwise the proposal now before this meeting."

The amendment was seconded by Mr. W. B. LEWIS.

After discussion, the amendment was put to the meeting, and was declared to be lost.

The original motion was thereupon put by the Chairman, and was carried.

11 February, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2882.*)

"The Manufacture of Aluminium by Electrolysis: and the Plant at Niagara for its Extraction."[1]

By ALFRED EPHRAIM HUNT, M. Inst. C.E.

THE Niagara River flows as a comparatively quiet stream from the outlet of Lake Erie at Buffalo to within about 1 mile of Niagara Falls. From this point there is a rapid descent of 56 feet to the brink of the Falls, where the water, with an average depth of about 20 feet at the crest of the Horse-shoe Falls, suddenly descends a distance of 160 feet into the gorge below. Upon the plateau above the Falls and opposite to navigable water just above the rapids, on the site of the old French Fort Schlosser, are situated the new works of the Pittsburgh Reduction Company, engaged in the production of aluminium. Part of the energy in the stream flowing past the works is now conducted from the turbines of the Niagara Falls Power Company, situated half a mile further down the stream, back along the river bank in the form of electric energy, and expended in the work of electrolysis of the refractory oxide, alumina, which is the substance here used as an ore for the production of aluminium.

ALUMINA.

The pure sesqui-oxide, alumina ($Al_2 O_3$), containing 52·95 per cent. of aluminium, is the best compound of aluminium for use

[1] Owing to the curtailment of the last Session the reading of this communication, which was received in February, 1895, was postponed until the above date; and in the interval descriptions of the Niagara Power Works, which form the subject of a part of the Paper, have appeared elsewhere.

in reduction to the metallic state; not only on account of the character of the by-product, oxygen, and the ease with which this by-product can be eliminated, but also on account of its comparative cheapness, and the facility with which a high degree of purity can be attained in its manufacture on a commercial scale. This can be accomplished by processes that are strictly chemical in character, and which lie, therefore, beyond the scope of this Paper. It has, however, been found that it is necessary to only use alumina that has been so purified, for the hard crystalline anhydrous oxides of aluminium, corundum and emery are too difficult to mine, and are too valuable as abrasive agents to make their use as ores of aluminium practicable; while the rarer ones, such as the ruby and sapphire, are, of course, quite out of the question. The monohydrate of alumina, diaspore, is a hard crystalline mineral which, although a pure oxide of the metal, has not yet been found in sufficient quantities to give it much importance as an ore. It consists of 85 per cent. of alumina with 15 per cent. of water of hydration.

The high heat of formation, and the extreme infusibility of alumina are not much more serious obstacles to its use than those which would be encountered in an attempt to utilize the haloid salts of the metal; and the use of the former body possesses the advantage of permitting continuity in the operation of reduction, which is not found to be possible when the double salts of aluminium with the alkalies or other metals are used, on account of the residual mass that then collects in the pot, and the operations, if conducted on a commercial scale, soon stop from clogging. The halogen salts and the sulphide have, so far, seemed to be the only compounds of aluminium other than the oxide ever likely to be used successfully, and all these substances are more expensive and generally less advantageous. The lower monoxide of aluminium (AlO), containing 63·22 per cent. aluminium, is not a very stable compound; when heated it oxidises to alumina, and practically would be used as alumina in metallurgical operations. The more complex rock minerals, such as felspar or mica, although the most common and abundant sources of the metal, are comparatively poor as ores of aluminium; and, on account of the cost of extraction of the pure salts, are (at least, at present) entirely out of the category of practicable materials.

Alumina is prepared from one or the other of the minerals bauxite, cryolite, native sulphate of alumina alum shales, or from the clays, of which some particulars are given in the Appendix.

Extraction of Aluminium from its Compounds.

Aluminium is one of the few metals whose oxide is not decomposed by intimate contact with hot solid carbon at the temperature of the regenerative furnace, or below what may be attained in the electric arc. The oxidation, moreover, of an equivalent of carbon does not furnish nearly the amount of energy required to reduce an equivalent of aluminium. The more important chemical laws bearing on the case are these:—A substance will usually only chemically displace another if it evolves more energy in its new combination than is absorbed by the necessary decompositions; also substances which evolve the greatest heat when they enter into combination are difficult to decompose, and absorb the greatest amount of heat when they are broken up—they possess what is termed by chemists, a high "heat of formation."

Aluminium stands high in the list of metals for its power of evolving heat when entering into combination with the metalloids and with acids, being only exceeded in this respect by caesium, rubidium, potassium, sodium and lithium; and, owing to other circumstances, to be considered later, aluminium is more difficult to reduce in a pure state on a commercial scale than most of the metals. If carbon could have its affinity for oxygen sufficiently increased, or if for two atoms of carbon there could be substituted one with double the reducing power, the reduction of aluminium by its agency would be made easy. Something corresponding with this is, indeed, done in the electrolytic method of reduction, by increasing the electromotive force between the electrodes sufficiently to break up the molecules of alumina; and when the device was adopted of dissolving the ore in a flux which had not a high-melting point and was sufficiently stable, the way was opened for the reduction of many metallic compounds which had previously proved refractory. If, in the future, a lower oxide or a less stable compound of aluminium can be obtained, the probability is that such ore will be equally adapted to its final reduction by electrolysis in a state of solution in a flux, as by the Hall process. The reduction of aluminium from its salts by hot solid carbon, or any other cheap reducing agent, is not only an expensive process, but the metal is difficult to obtain pure; for the reason that any re-agents or set of conditions which will cause its reduction, are sure also to cause that of any other metals whose salts may be present—thus requiring, in most operations that could be devised for the purpose, the employment of not only a pure salt of aluminium to be used

as an ore, but also that of pure reducing agents. To add to this difficulty in the production of pure aluminium, if the reduced metal is heated much above its melting point (627° C.), it develops the troublesome property of occluding the gases with which it may be in contact, thus rendering the product porous, weak, and unsound in structure.

Owing to its lightness, it is difficult in many operations to ensure the separation of aluminium from the by-products the specific gravity of which is nearly the same as its own. This trouble has been encountered when attempts have been made to electrolyze aluminium compounds in electrolytes that have about the same specific gravity as the metal, as well as in the chemical reduction of alumina by means of metallic magnesium. In this latter connection it may be mentioned that an interesting new compound of alumina (the monoxide AlO) is produced, besides some finely divided aluminium, when alumina is heated with magnesium. The properties of this easily oxidizable brownish-black monoxide of aluminium have not yet been established, but when this is done, a cheaper method for the manufacture of the metal may possibly be devised.

A well-known fact in connection with the production of aluminium may here be noted, viz., that potassium will reduce the halogen compounds of all of the metals, even of those whose oxides cannot be reduced by either carbon or hydrogen. The cheaper production of the electro-positive metals, potassium, sodium, aluminium and magnesium will in the future undoubtedly lead to their more extensive use as reducing agents; and magnesium is being now successfully made from the mineral carnellite. The high heats of formation and the stability of its oxides and chlorides render the action of magnesium upon the oxide and chlorides of other metals particularly promising as a reducing agent.

The difficulties found in the electrolytic separation of aluminium not only include those due to the necessity for fluidity and conductivity in the mass to be electrolysed, but also those due to the infusible character of all of the practicable salts of aluminium. This especially is the case with the oxide, alumina, and with the fluoride; and not only so, but, as is the case of aqueous solutions of aluminium salts, they are more difficult of decomposition than their solvents. Some fused salts, and even some compound liquids, at ordinary temperatures, are for all practical purposes non-conductors and will scarcely permit the passage of an electric current; many others have so high a resistance as to occasion an altogether

prohibitive loss of energy in overcoming it. The French chemist, St. Claire Deville, suggested the electrolysis of aluminium chloride ($Al_2 Cl_6$); but this salt, when in a heated or molten condition, is, for practical purposes, hardly a conductor of electricity at all. Voltaic action resulting from chemical union (the exact opposite of electrolysis, which occasions dissociation) must of course also be reduced to such proportions as not materially to impede the reduction of the metal. This is a condition difficult of attainment in some processes, for voltaic action is sure to be produced, in many suggested methods, by the substances set free at the electrodes. No considerable quantities of corrosive gases should be evolved by the process, or great expense will be occasioned by the need of frequent repairs to the apparatus; and it is costly to conduct away such gases and to replace the salts whose acids would have been wasted; the gases occasion moreover very serious annoyance. In electrolytic operations where such corrosive gases are formed, the further difficulty of securing a good and insoluble anode has so far proved an insurmountable obstacle to successful operations.

The use of alumina as the ore not only has the advantages which have been enumerated as necessary, but the special advantage that oxygen only is evolved. This gas is liberated in presence of the carbon anode and under the requisite conditions to produce carbonic acid, which is a comparatively harmless waste product that may be allowed to escape into the air of the apartment in which the operation is being conducted.

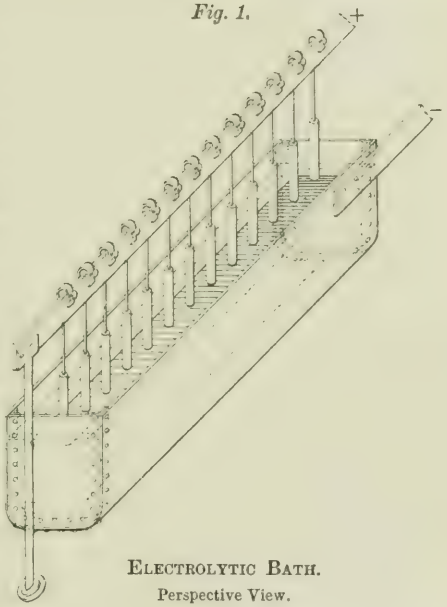
The necessity of continuity of operations, especially in an electrolytic process, has already been referred to. Any process that "clogs up" or requires frequent stoppages, cannot, in the nature of the case, be very successful for the manufacture of aluminium. Indeed, the difficulties, as will be seen in the discussion of the Hall process, are so varied and great, that the ores and reagents which have been so far used successfully in the electrolytic separation of the metal are limited to combinations of a very few halogen salts of aluminium, together with similar salts of some of the metals more electro-positive than aluminium.

Manufacture of Aluminium by the Hall Process.

The Hall process may be described as being the electrolysis of alumina dissolved in a molten bath of the fluoride of aluminium and the fluoride of one or more metals more electro-positive than aluminium, generally sodium or potassium, and calcium. A large continuous electric current is passed through the molten mass

with a small difference of potential, and the deposition of aluminium in a molten condition is thereby brought about. Pure alumina is dissolved in the proportion of about one-third of the weight of the solvent, and is decomposed under the electrolytic action of the current into its elements, aluminium and oxygen, the solvent itself remaining unchanged; the bath is maintained in a constant condition by frequent additions of fresh supplies of alumina. The solvents preferably used are either a mixture of the fluorides of aluminium, sodium and calcium, produced artificially or from the minerals cryolite and fluorspar, or a mixture of the fluorides of aluminium, potassium and calcium, produced by chemical action of hydrofluoric acid upon the compounds of potassium and aluminium, pearl ash and alumina being the salts preferably used, together with a portion of the mineral fluorspar.

Fig. 1.



Electrolytic Bath.
Perspective View.

The process is carried on in carbon-lined iron pots, *Fig. 1*, placed in series; the pots, with their carbon linings, as well as the reduced metal lying in them, serve to form the negative electrodes or cathodes; and, in the process as usually carried out, the anodes are of carbon, and dip into the bath. Some of these latter are connected by round copper rods and screw clamps with the omnibus bar of the positive ends of the circuit. The negative connections are made by heavy copper bars, riveted to the iron pots, and are in circuit with the positive poles of the next pot; the current going thus in series from one pot to the other back to the negative side of the dynamo. The carbon anodes are lowered in the bath from time to time as they burn away at their lower ends where the oxygen is liberated from the alumina.

The main electrical circuit is formed of heavy copper bars, which are supported upon insulated slate supports above the

ground. The area, A, of these conductors is determined by the formula

$$A = \frac{C \times N \times D}{E \times V}$$

where C is a constant, and

A = the area of conductor in square inches,
N = the electrical horse-power to be delivered,
D = the length of the transmission line in feet,
E = the electromotive force at the delivery end of the line, and
V = the loss of pressure in volts on the line due to its resistance;

with 10 per cent. added as a factor of safety. The oxygen separated by the electrolytic action attacks the carbon anodes, uniting with them and forming carbon monoxide; the reduced aluminium sinks through the electrolyte, because of its greater specific gravity, and going to the bottom of the pot remains in a molten condition. The fluoride solvent salts are not decomposed by the current, but remain practically unchanged; the small losses being those occasioned by volatilization and by solidification in the form of "cake" at the bottom of the pots. The materials employed in the process are the alumina and the carbon anodes. These latter are used up in a proportion of a little less than 1 lb. of carbon to 1 lb. of aluminium produced. A small quantity of chemical stores is also needed, at a cost of a fraction of 1*d.* per pound of aluminium produced. The pots, with their linings, last for months of continuous work, the carbon linings of the pots not being worn away appreciably. The only other items of cost for the manufacture of the metal, besides general charges, are those of labour and for the electric current.

The electrolytic process for the separation of aluminium is the only metallurgical operation known to the Author for the reduction of a metal from its ore upon a large commercial scale without any loss of metal. The operation is as complete as an assay, every portion of the aluminium added in the form of its oxide being reduced and obtained in ingot form from the reducing pots. There is no volatilization of metal and no loss in the form of slags or other by-products when the process is being properly conducted. The theoretical quantity of carbon anodes necessary for the decomposition of alumina is $\frac{3}{4}$ lb. of carbon to 1 lb. of aluminium produced, according to the equation

$$Al_2O_3 + 3\,C = 2\,Al + 3\,CO.$$

The carbon monoxide, when it comes in contact with air, burns to carbon dioxide.

When the amount of alumina in solution in the bath becomes deficient, the electrical resistance is greatly increased; and as the current is kept nearly constant by the dynamos, the difference of potential at the bath rises. When a fresh supply of alumina is dissolved in the bath, the resistance and the voltage rapidly fall again to the normal value. Continuity of operation is one of the essential features in any process for the economical separation of aluminium by electrolysis. It will be safe to say that any process that may be devised for the purpose and that does not possess this feature cannot succeed in competition with one that has it.

The molten aluminium that collects at the bottom of the pots is dipped or siphoned out, as water would be removed from under a layer of oil, due precautions being taken to keep the superincumbent and molten electrolyte from being taken out with the metal. This work is done without interrupting the current passing through the bath. Since the temperature of the molten electrolyte is less than 982° C. it is well within that which a retaining vessel and anodes of metal are able to withstand. The process can therefore be carried on in thick cast-steel pots without carbon linings and with metal anodes. In this case the aluminium produced is somewhat impure, as it becomes alloyed with the iron or other metals with which it is brought into contact. The solvent portion of the electrolyte can be melted in an exterior crucible or furnace, and then poured into the reducing-pots, or it may be readily or conveniently melted in the reducing-pots by the heating action of the current when first commencing work.

It is a comparatively easy task to produce pure aluminium by the Hall process, on account of the few sources of contamination and the ease with which they may be controlled. The fluoride solvent salts are made from commercial products or from minerals; cryolite contains silica in the form of quartz and iron in the form of spathic iron ore, together with a little lead, zinc and copper. The other minerals used, as well as the carbon anodes, contain some silicon and iron in oxidized forms. But as all these metals are electro-negative to aluminium, they are the first to be reduced, and are all removed with the first metal produced in a fresh bath; so that after a couple of days' use, the bath is as good as if it had been made from chemically pure materials. The constant and more serious sources of impurities are the carbon anodes and the alumina, for both contain a small quantity of the oxides of silicon and iron. By care in the preparation of these materials, metal is regularly obtained with an average of 99 per cent. of aluminium; and some has been prepared by the Pittsburgh

Reduction Company with as much as 99·93 per cent. of the metal. The impurity in the metal obtained by the Hall process consists of silicon, partly in the graphitoidal or crystallized form, together with a little iron.

The size of the reducing-pots used in the Hall process varies with the scale of operations, a good rule being that 1 cubic foot of the solvent employed at these works will dissolve sufficient alumina for the production of 1 lb. of aluminium per hour. The number of solvents that can be successfully used is limited.

The requirements that have to be met by a suitable solvent are the following:

1. The solvent, with its considerable charge of dissolved ore, must be fluid at a comparatively low temperature, in order to obtain the necessary conductivity and to allow the reduced aluminium to sink through it to the molten bath below.
2. It must dissolve and keep in solution considerable amounts (at least 20 per cent.) of the ore, at the working temperature.
3. Its "heat of formation" must be such that it will not decompose more readily than the dissolved ore when submitted to electrolysis. This requirement effectually prohibits the use of any aqueous solvent, and practically involves the use of molten salts.
4. Its specific gravity, when molten, must be less than that of the reduced aluminium, both to prevent short-circuiting and also the oxidation of the metal, which would happen if the latter were allowed to come to the surface.
5. There must be no solid by-product to clog the pot and thereby prevent continuity of operation.
6. The molten solvent with its contained ore must be a good conductor of electricity.
7. It must not have any corroding action on the nascent aluminium produced.
8. It must be cheap and readily procurable in large quantities.

Both alumina and fluoride of aluminium alone are too infusible to meet the requirements; and it becomes necessary that the alumina, which is by far the best and cheapest ore of the metal, should be dissolved in fluoride of aluminium to which the fluorides of some of the more electro-positive metals have been added. The electromotive force necessary for the decomposition of alumina is found to be 2·8 volts, but for that of aluminium fluoride, sodium fluoride and calcium fluoride it is much greater, being in each case 4 volts or more. A greater difference of potential is,

however, necessary for conducting the operation on account of the resistance of the bath and of the connections.

The electro-chemical equivalent weight of aluminium is 9·0; that of hydrogen being 1·0, and copper 31·5. Theoretically there should be 0·33912 gram of aluminium produced per ampere-hour, or 0·7476 pound per 1,000 ampere-hours. With the same electric current, under similar conditions, this amount of deposition of aluminium to that of copper would be as 9·0 to 31·5. The theoretical amount of aluminium reduced by any given current is determined by multiplying its electro-chemical equivalent (9·0) by the weight of hydrogen separated by the same current in the same time (0·037296 gram of hydrogen being separated per ampere-hour), and thus the amount of energy required to reduce 1 lb. of aluminium from its oxide is about 5 HP. hours. In practice a very satisfactory approach in output to the theoretical figures is made when the current expended in heating to keep the electrolyte in a molten condition is taken into consideration.

The losses of electrical energy to which the Hall process is subject, beyond the amount actually required for the electrolysis of the alumina, may be apportioned as follows:

1. Energy converted into heat by the resistance of the conductors and the bath.
2. Energy lost in replacing the metal corroded at the kathode (very slight).
3. Loss by counter electromotive force at the surfaces of the electrodes. This loss, if the process is well conducted, is very small. Where hydrogen is added to the electrolytic operation, as has been proposed, the loss under this head is heavy, for hydrogen accumulating around the cathode causes excessive polarization.
4. Loss in transporting the aluminium to the kathode and the oxygen to the anode (very small). There is a good circulation, however, maintained in the electrolyte when the process is working satisfactorily.
5. Loss by secondary reactions between the electrolyte and the products of the electrolysis (small).
6. Losses by short-circuiting the current, so that it does not wholly traverse the electrolyte (small when skilful work is done; but by any process where the reduced aluminium is liable to come to the surface of the bath or to remain intermingled with it, such losses would be considerable).

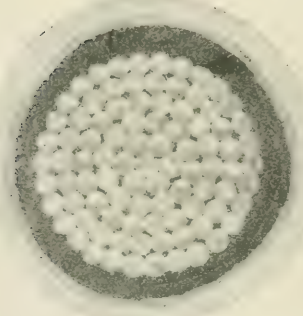
Losses by leakage of the current through conductors to the ground are, on account of the low voltage of the current employed,

almost entirely prevented when the insulation and all the joints of the conductors are good.

The Pittsburgh Reduction Company's Upper Niagara Works.

Subway and Conductors.—Owing to the works being only half-a-mile from the dynamos at Niagara, the electric energy used by the Pittsburgh Reduction Company is not raised in potential by means of step-up transformers, as is intended to be the case when transmitting from Niagara to Buffalo and other distant places; but the leads are directly connected to the dynamos. A stone bridge takes these leads over the intake canal of the power-house, and they pass on to the works of the company through a subway built of concrete, the crown of the arch of which is 3 feet below the surface of the ground in order to avoid any action from frost. This subway is $5\frac{1}{2}$ feet high and 3 feet 10 inches wide inside. The bottom of the subway is inclined and is of a curved shape to allow for the drainage of any condensed water. It is intended, however, that this subway should be kept perfectly dry if necessary by the continuous passage of warm dry air through it. The walls of the conduit are of Portland cement concrete 10 inches thick with a floor of masonry 1 foot thick. The sides, for a height of about 3 feet, are further protected by stonework 1 foot thick.

Fig. 2.



Full size.

The conductors, *Fig. 2*, have an external diameter of $1\frac{1}{4}$ inch. Several cables are already laid temporarily on the wooden floor of the subway. Each cable consists of a large number of strands of pure copper wire, and is equivalent to a bar 0·975 inch in diameter. The cables will eventually be supported by brackets well insulated from the walls of the conduit and placed 10 feet to 30 feet apart. The walls of the conduits have apertures at convenient distances, so that the line can be readily tapped at intermediate stations. Manholes 400 feet apart are provided to this conduit from the surface of the ground.

The cables are insulated with rubber and covered with an outer coating of lead. They are made in lengths of 800 feet. When

working under the load for which they are designed, each will carry about 560 amperes. The section of the copper conductors is calculated upon a basis of a current density of 350 amperes per square inch. This density was decided upon, after comparing the cost of cables with the estimated value of power lost, which is estimated in the cables to the works of the company to be one-tenth of one per cent. The drop in potential along the cables will vary with the inductance of the circuit. The distance from the dynamos through the transforming-house of the Power Company to the stationary transformers of the Reduction Company is 2,703 feet. The current is alternating, with two separate circuits differing in phase by 90°, and a maximum difference of potential of 2,500 volts.

The Transformers.—Each set of transformers deals with 500 HP., and comprises two static transformers and one commutating machine. The 2,500-volt alternating currents are first conducted to the pair of stationary "step-down" transformers, by which the potential is reduced to 115 volts at the secondary terminals with a corresponding increase in the current. These transformers consist as usual of a laminated iron core, around which the primary (in this case the high-tension) and the secondary (low-tension) coils are so wound that the core carries the magnetic lines of force from the one set of coils through the other set, just as in the ordinary induction-coil. The primary wires comprise a large number of turns of fine wire, while the secondary coils consist of a smaller number of turns of coarser wire. These static transformers are formed into sections, and the laminated sheets of soft iron are so divided that spaces are left for air-blasts from below to pass up through them as well as through the perforations in the bed-plates of the machine, and thus assist in the dissipation of the considerable amount of the heat developed. The transformers are placed over a long pit, 8 feet wide and 3 feet deep, supplied with air at a pressure of $\frac{1}{2}$ oz. per square inch. The iron cores of the transformers are 27 inches by $39\frac{1}{2}$ inches by 53 inches, and each transformer occupies a floor space of 36 inches by $52\frac{3}{4}$ inches. The magnetic lines of force created by the current in the primary high-tension coils surrounding the iron cores are carried through the convolutions of the secondary coils; the rate at which these magnetic lines of force are cut by the secondary circuit, as compared to the rate in the primary one, determines the relative potentials in the two circuits, matters being so arranged that an electromotive force of 115 volts is produced in the low-tension secondary circuits.

Tests of these fixed transformers have shown that, in a room the temperature of which was 24° C., and after a nine hours' run with the use of an air-blast supplying 1,040 cubic feet of air per minute, the temperature of the transformers was raised to a maximum of only 61° C.; while a similar test without the aid of the air-blast showed the transformers to be raised to a temperature of 92° C. By the aid of artificial means for cooling, a much greater capacity, as a transformer, per unit weight of apparatus employed is obtained. These machines have an efficiency of over 97 per cent. at full load, and are guaranteed to have a no greater rise in temperature than 40° C. above that of the surrounding atmosphere when working continuously.

Connection between the tunnel leads and the transformer-house is effected by lead-covered copper cables of 1 inch external diameter—the copper rods being each $\frac{17}{32}$ inch in diameter. The cables are divided into four groups, two for each side of the two-phase system employed. These conductors run through the pit beneath the transformers to switch-boards, where they are connected to the static transformers by double-throw switches. The low-potential side of the converters is connected by double-throw switches to 4-inch by $\frac{1}{2}$-inch copper bars, which are bolted on to insulated slate slabs for support. These omnibus bars connect the transformers already described with the alternating side of the commutating machines, a switch-board for these bars being mounted beside each pair of transformers. The low-tension 115-volt alternating currents thus transformed in the stationary transformers are conducted to the collector side of the commutating machines, which are quarter-phase motor generators with twenty poles. They run at a speed of 150 turns per minute, and each machine produces a direct current of 2,500 amperes. The coils for the continuous current are wound on the same armatures as those for the alternating currents, the former being taken off by a number of brushes from the commutator. The diameter of the armatures is 90 inches, and the machines themselves are 11 feet 6 inches high, with circular field-magnet frames extending a little below the floor-line. Each rotary converter occupies a floor space of 13 feet 6 inches by 9 feet 10 inches.[1]

The continuous-current circuit of each machine is connected by cables, with conductors of 1·225 inch equivalent diameter, to the switch-board, and thence to the pot-room of the Pittsburgh

[1] See also Transactions of the American Institute of Electrical Engineers, vol. xii. p. 603.

Reduction Company. The current is here measured by ampere-meters, and its potential by volt-meters; all the circuits being coupled in parallel before being conducted by large copper omnibus bars through the brick wall of the transformer-room to the adjacent "pot" or reduction-room. In order to economize space, the indicating instruments on the switch-board have their scales arranged in a vertical plane at right-angles to the switch-board instead of parallel to it, as is generally the case; and the contacts of the field regulators for the motor generators are arranged vertically on a pedestal and their adjustment is made by a rack and pinion. The ampere-meter itself is arranged as a shunt from the main circuit for the same reason.

Measurement of the Electric Energy.—The quantity of energy used by the Reduction Company in their work is capable of measurement in several different ways. First, at the power-house, the turbine can be used as an energy meter. Having once ascertained the discharge of the wheel and consequently the horse-power generated, at the different amounts of gate opening, under a known head, by measurement over a weir, a daily record of the gate openings and head of water acting on the wheel will give data from which the power transmitted to the dynamo is readily computed. The efficiency of the dynamos is known to be 97 per cent., the loss by conduction over the cables to the transforming machinery at the Company's works has been ascertained to be only $1\frac{1}{2}$ per cent., and the 2,500-volt alternating current is known to be subject to a loss of only 3 per cent. at each stage, or a total of less than 6 per cent. for each set of step-down and rotary transformers; it is therefore possible to know, approximately, the energy received at the Reduction Works, from the measurements made at the turbines. Secondly, the energy can be measured by the record of the volt-, ampere-, and watt-meters, which are so constructed as to continuously record the voltage and the current, and the product of these two quantities respectively. The Power Company will charge the Reduction Company on the basis of watts consumed per minute. Thirdly, one means of estimating the continuous current delivered, and the most satisfactory to the Pittsburgh Reduction Company, would be derived from the record of the actual weight of aluminium produced per month, for the weight of aluminium electrolytically produced per horse-power-hour will be well known. By this method the aluminium product from the works would in effect form an electro-chemical meter.

Continuity of Supply.—Notwithstanding its magnitude, the installation is one of comparatively simple machinery, and during

the six months that have elapsed since the works commenced to deliver energy the supply has been uninterrupted and satisfactory in every way.

The New Kensington Works of the Pittsburgh Reduction Company.

The Pittsburgh Reduction Company have another large plant for the manufacture of aluminium at New Kensington, on the banks of the Allegheny, near Pittsburgh, Pennsylvania. At these works the dynamos are driven by steam-engines, coal being the source of energy at some times, and natural gas at others. The best quality of Pittsburgh steam coal only costs, in the form of slack with less than 8 per cent. of ash, 2*s.* 8*d.* per ton delivered, and it is automatically handled and fed by mechanical stokers to the furnaces under the boilers. Pipes also connect the works with the gas mains from one of the largest natural gas districts of Western Pennsylvania, and which are within a distance of 10 miles. In the summer season there is an excess in the supply of gas over the general demand for it in the district, and it is then used as even a cheaper fuel than the coal.

At New Kensington the company are able to pump excellent water from the adjacent river, and as their engines are of one of the most approved high-speed compound types, with labour and general costs comparatively low, the large units of steam power at these works are probably produced under as favourable conditions as are to be found anywhere else in the world. As an instance of the low cost, it may be mentioned that their boiler repairs only cost about 2*d.* per HP. during the year 1894. The high-speed dynamos at these works are satisfactory in their working, and their repairs for the year 1894 only amounted to a rate of 6*s.* 3*d.* per E.HP. The various items of cost of this installation are carefully watched and tabulated, and the records of the volt-meters and ammeters not only give a good measure of the electrical power generated, but the amount per month or year of aluminium produced under constant electrolytic conditions is also one of the best indicators of the average HP. expended, so that it is possible to obtain accurate knowledge of the amount of energy used and of its cost.

The competition, therefore, in the use of power from the two different sources at New Kensington and at Niagara Falls respectively will be very interesting, and the general public will be able to gain some idea as to the results, by noting "the survival of the fittest," so to speak, and observing where the

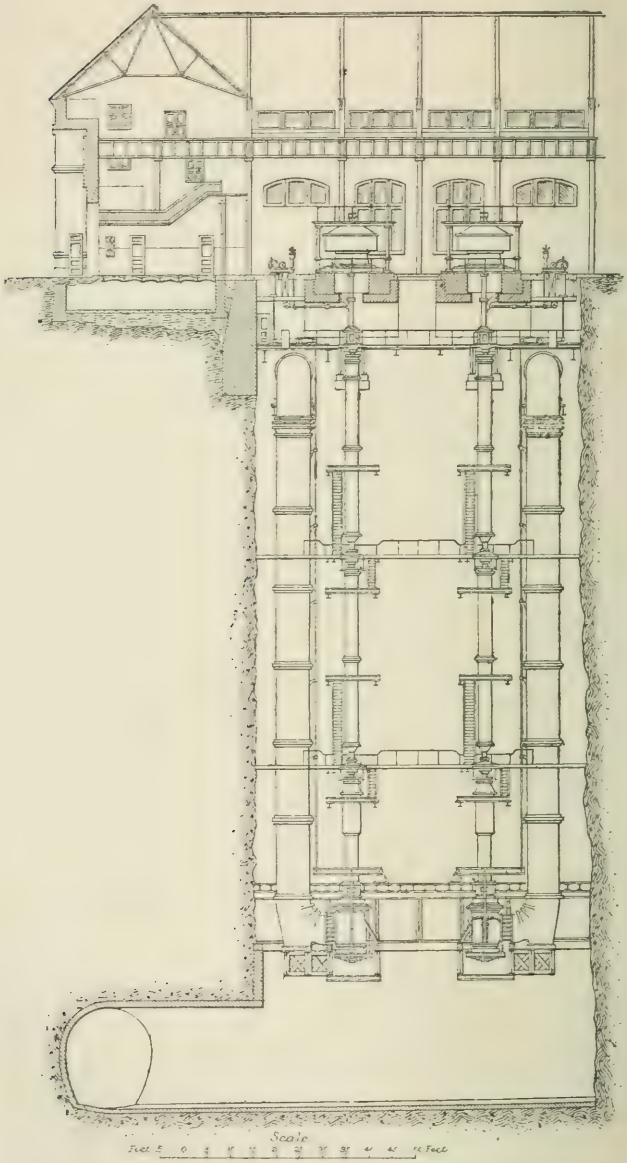
Pittsburgh Reduction Company may, in the future, choose to increase their plant to accommodate their rapidly growing business.

The Niagara Power Works.

The Falls of Niagara recede up the river at a varying rate as the water erodes, at the brink of the Falls, the soft shale, or the harder Niagara limestone, or the still harder slate rock of the district. The average yearly rate of recession of late years has been about 12 inches, and the works of the Niagara Falls Power Company have consequently been placed at a considerable distance above the Falls, so as to be unaffected by the probable changes in the cataract for many centuries. The water-power is obtained from a mill-pond formed by the chain of the five great lakes of America, the united area of which exceeds 90,000 square miles. These lakes have a drainage area more than twice as great as the combined area of Great Britain and Ireland, with a yearly rainfall of about 31 inches. The mill-dam is the great ridge of limestone that stretches across the country between Lakes Erie and Ontario. Over the top of this ridge, the Niagara River, with a flow of some 270,000 cubic feet of water per second, has in the past cut its way, and this large volume of water plunges over the Falls, a distance of 216 feet from the level of the still water above to that of the gorge below.

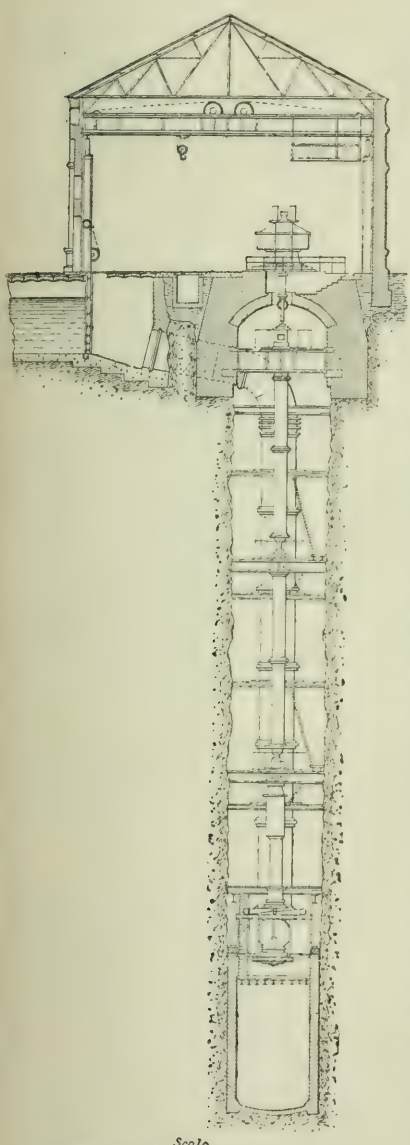
The Lake Survey Board, U.S. Engineer Corps, estimates the average flow to be about 270,000 cubic feet of water per second, which is approximately equivalent to over 1,000,000,000 lbs. per minute. Reckoning the available fall to be 161 feet, then the horse-power would be approximately about 5,000,000, equivalent to the energy of about 200,000 tons of coal per day, or, as is estimated, of about the daily output of fuel of the entire world. Assuming the flow of water over the Falls to be 16,200,000 cubic feet per minute and the capacity of the tunnel is intended to be 500,000 cubic feet per minute, it will be seen that only 3 per cent. of the water of the Niagara Falls is to be utilized by the Niagara Falls Power Company with their new plant. Major E. H. Ruffner, of the Corps of Engineers, U.S.A., in charge of the work of the new Chicago Drainage Canal, designed to turn a portion of the water of the Great Lakes along an old glacial outlet through the Chicago, Desplaines and Illinois rivers into the Mississippi river, and which will probably be completed in about three years, estimates that it will lower the level of the water in the lakes $\frac{7}{10}$ foot;

Fig. 3.



LONGITUDINAL SECTION OF WHEEL-PIT.

Fig. 4.



CROSS-SECTION OF WHEEL-PIT.

a very much larger amount of water will then be diverted from Niagara Falls than by the works now under consideration.

The Niagara Falls Power Company has obtained rights of way and powers to construct another tunnel, which will at least double, if not quadruple, the capacity of the one already driven. What is practically the same company, though under the name of the Canadian Niagara Falls Power Company, has obtained from the Dominion Government the right to construct a 250,000-HP. tunnel on the Canadian side of the Falls, and is under agreement to utilize power there before January 1898. Although the amount of energy transmitted backwards up the stream at Niagara for the purpose described in this Paper is but a very small part of the vast supply available from the water flowing down the river at this point; yet, compared with the electric energy so far generated by dynamos, it is one of the largest supplies flowing through any single set of conductors in the world; and the electric generators that transform the power from the rotary shaft above the turbines are the largest yet built. Three of the dynamos are now placed over

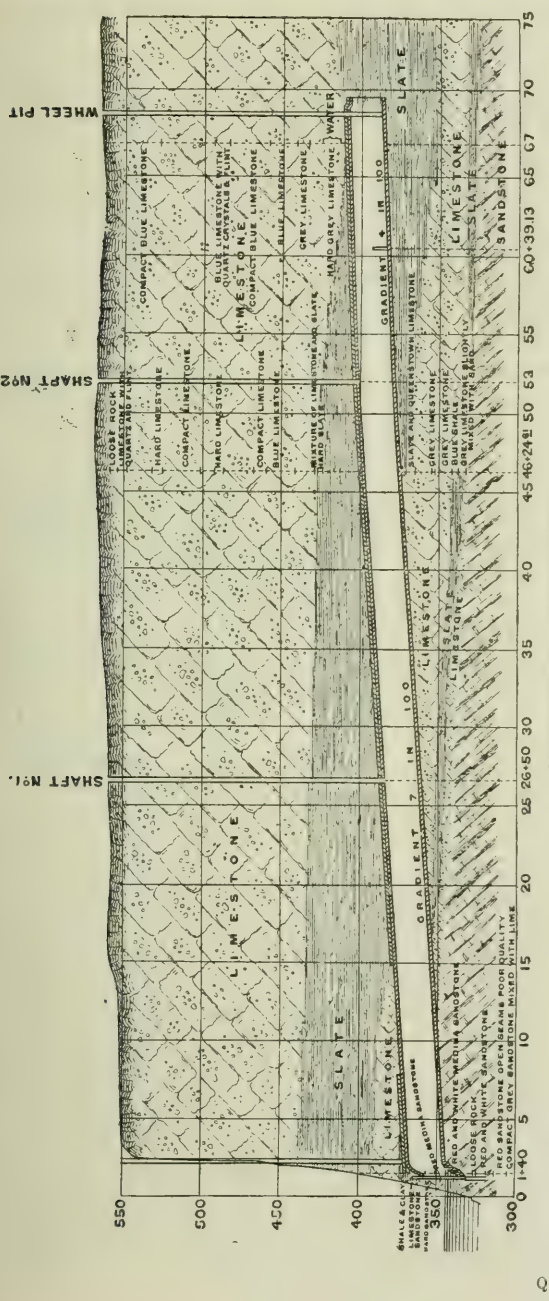
the shafts from the turbine-pit, each being of 5,000 horse-power.[1] Ultimately, ten such dynamos are to be placed in one long pit cut through the solid rock down to the tunnel level, and forming the largest wheel-pit ever undertaken. So far it has been excavated for a length of 180 feet; it is 21 feet wide at the top and 16 feet wide at the bottom and 180 feet deep, and will be continued in a direction parallel to the intake canal until it has a total length of 414 feet.

The water is taken from the Niagara River by an inlet canal, commencing at a point about $1\frac{1}{4}$ mile above the "American Falls." The canal is 188 feet wide at the river end and 100 feet wide at its termination. It extends up stream from the river and the water backs into it under a floating boom, by which arrangement it is kept free from ice. The inlet canal will ultimately be about 1,500 feet long. It has a uniform depth of 17 feet, the water in it being 12 feet deep. Its present length is 1,260 feet. The sides of the canal are built of masonry, and are 7 feet thick at the base and 3 feet thick at the top, on which there is a coping 30 inches wide. The masonry of the upper portion of the turbine-pit is formed with apertures 17 feet deep and 14 feet wide, connecting it with the intake canal. Each aperture is controlled by gates and guarded by iron gratings, through which the water is admitted to the penstocks, each 7 feet 6 inches in diameter, and in this manner is conducted by vertical pipes to the turbines in the wheel-pit, *Figs. 3* and *4*, the fall to the turbines being 136 feet.

The Tunnel.—After the water has done its work at the turbines, it passes into a tunnel that serves as a tail-race for the 500,000 cubic feet of water which, it has been stated by the late chief engineer of the Cataract Construction Company, will flow through it per minute, when used to its full capacity.

Ground was first broken on the 4th of October, 1890; and the contract for constructing the first 6,700 feet of the tunnel was carried out by Messrs. Rogers and Clement of New York, the remainder by Mr. A. C. Douglass. The portal, where the water of the tunnel is discharged into the river, rests on a ledge of sandstone, 40 feet below the level of the river in the gorge, and the floor of the opening of the tunnel is 205 feet below the sill of the gate to the main canal. It is constructed in a very massive and solid manner of masonry. The lower half of the tunnel for a

[1] Work has now been commenced on the enlargement of the wheel-pit for the second installation of the three 5,000-HP. wheels, December 1895.



Horizontal Scale, 1,200 feet to 1 inch.
Vertical " 120 " " "

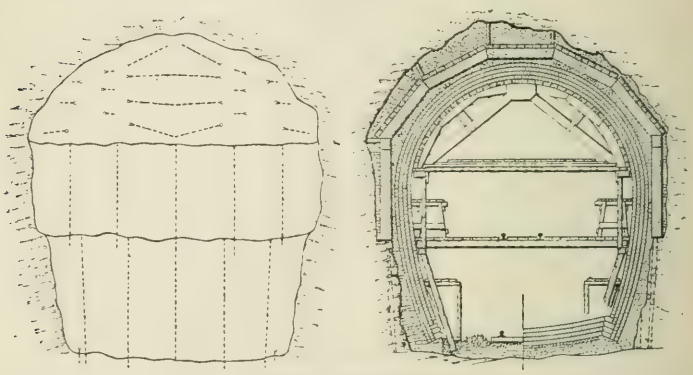
Fig. 5.

THE NIAGARA POWER WORKS—LONGITUDINAL SECTION OF THE TUNNEL.

distance of 100 feet from its mouth is, moreover, lined with heavy steel plates.

The tunnel already executed, *Fig. 5*, falls into the Niagara River at a point a little below the carriage suspension bridge, and 1,150 feet below Prospect Point on the eastern side of the American Falls. Its total length will be about 9,500 feet. It has an average gradient of 36 feet to the mile, and it is expected that when in full service, the water will flow through it at a speed of 26 feet 6 inches per second. The portion of the tunnel near the wheel-pit has a gradient towards its mouth of 4 in 100, and in the portion nearer its outlet a gradient of 7 in 100. Its cross-section, *Figs. 6*, is of horse-shoe form, 21 feet high, 18 feet 10 inches wide at its widest part, and 14 feet $9\frac{1}{4}$ inches wide at the bottom. When

Figs. 6.



Scale, $\frac{1}{10}$ inch to 1 foot.

CROSS-SECTIONS OF THE TUNNEL.

the driving of this tunnel was commenced, it was hoped that the use of lining could be avoided, the first 1,200 feet of the excavation being through a comparatively hard rock with seams of slate; whilst the remainder of the work was through a compact shale, underlying the Niagara limestone at a depth of about 130 feet. But it was found that this material, although hard when first exposed to the air, disintegrated and slackened when weathered, and caused dangerous falls of large masses of partially decomposed rock. It was, therefore, necessary to line the 7,000 lineal feet of tunnel with four to six rings of brickwork laid in cement. More than 14,000,000 bricks and some 45,000 barrels of Portland cement were used for this work, which not only occasioned an extra expense of £100,000, but reduced the capacity of

the tunnel as a tail-race from the first estimate of 120,000 HP. to 100,000 HP.

Three shafts were sunk for the purpose of driving the tunnel; one at the lower end, one at 2,600 feet (No. 1), and one at 5,200 feet from that point (No. 2), leaving 1,700 feet to reach the wheel-pit; and since the larger portion of the work had to be done from the latter shaft, its equipment was the most complete. Headings were driven in both directions from Nos. 1 and 2 shafts; one from the turbine-pit and one from the lower end or portal. The headings were driven the full width of the tunnel and the remainder of the rock was removed in two benches, the "centre-cut" system being employed, with four to six rock-drills at each heading driven by compressed air at a pressure of 75 lbs. to 100 lbs. per square inch. The excavating machinery employed consisted of three 18-inch by 30-inch duplex air-compressors and twenty-five Little Giant rock-drills made by the Rand Drill Company. The exhaust of these drills served to provide satisfactory means for ventilation. The explosive used was dynamite. The average progress made was over 10 feet of finished tunnel per day during the twenty-three months occupied in driving and lining it; 166,577 cubic yards of material were taken out, sufficient to fill in and reclaim about 31 acres of ground on the river front, and 1,854,453 cubic feet of timber were used in the construction of the tunnel, shafts and turbine-pit. The alignment in the tunnel was in every way satisfactory throughout, although the clearance allowed between the timbers and brickwork was only 4 inches. This alignment was produced by the aid of two steel wires extending down the vertical shafts, with 30-lb. plumb-bobs attached, which were suspended in oil at the foot of the shafts.

The Niagara Falls Paper Company has been the first to utilize the new tunnel, having built a turbine-pit and erected three 1,100-HP. turbines. These wheels were constructed by Messrs. R. D. Wood & Co., of Philadelphia, and designed by Mr. E. Geyelin. They are of an inverted Jonval type, with vertical shafts. The water is admitted below the wheels, and thus the up-pressure counterbalances the weight of the 10-inch diameter shaft, 175 feet in length, with bevel gear. The wheels make 260 revolutions per minute, and the penstock supplying them is 13 feet 6 inches in diameter and is intended to supply one and possibly two more turbines. Two of those now in operation grind each from 18 to 20 tons of pulp every twenty-four hours. The third turbine drives the general machinery in the mill, such as pumps, rag machines, dynamos, &c. After twenty-five months' steady work

of twenty-four hours per day these turbines continue to perform their duties satisfactorily.

The Turbines.—The turbine principally used hitherto in the United States has been of the twin form, arranged with a horizontal axis projecting from the wheel-case in such a manner as to permit direct connection with other machinery, or the attachment of pulleys by which belts or ropes may be driven. These turbines have been used wherever large volumes of water were obtained with a comparatively small fall.

The form of water-wheel arranged for high falls, which finds most favour in the United States, is that known as the Pelton wheel. This has always been built with a horizontal axis. It was not, however, considered advisable to employ it at Niagara, where a Pelton wheel with a vertical axis, and provided with the large number of nozzles necessary for the development of 5,000 HP. at each shaft, was considered too great an innovation to be adopted with safety.

The great space required underground for belts or ropes, if either of those means for transmission of power from wheels with horizontal axes were adopted, and the expense and trouble of placing the dynamos in damp chambers entirely dependent on artificial means for illumination, were thought to offer such serious sources of difficulty, that it was decided to use vertical shafts which should transmit the power to the surface from turbines with vertical axes. The chief difficulty that then remained to be met was the construction of suitable bearings, or footsteps, by which to sustain the pressure due to the column of water, as well as the weight of the shaft and that of the revolving parts of the dynamo attached to it. Several methods were proposed by various designers who competed for the supply of the machinery. Some arranged for oil- and water-bearings distributed along the line of the shaft; others preferred hollow shafts, provided with an oil-bearing on the top of the supporting column, terminating near the top of the turbine (using the so-called "Fontaine step"); a water-piston bearing found favour in other quarters, while some designers suggested the use of two wheels, one larger in diameter than the other, and placed vertically over it, so that a resultant upward pressure of the wheel should neutralize the weight of the superincumbent load.

The plan finally adopted, involving the use of several of these proposed features, is as follows:—Two Fourneyron turbine-wheels, each in three stories, are placed in the same vertical axis; one wheel is above, and the other below the guide-wheel casing, in which the elbow from the supply-pipe terminates. The upper

guide-wheel is perforated, so that the disk of the upper turbine-wheel forms the top of the chamber, and receives the pressure of the water on the whole of its under surface. The lower guide-wheel, on the contrary, is solid, and forms the floor of the casing through which the central shaft passes for the attachment of the lower turbine-wheel outside. The resultant downward pressure in the guide-wheel chamber is thus transferred to the foundation, while the upward component acts directly on the shaft and serves to relieve the bearings of its weight.

The constant pressure of the water in the penstock discharging between the twin turbine-wheels serves to support the entire superincumbent weight of the revolving parts of the apparatus, so that when the load is light the upward thrust of the water is 3,500 lbs. in excess of the weight on the shaft, and as the load increases to its maximum the resultant upward thrust disappears and becomes a downward pressure of 3,500 lbs. These varying pressures are taken up by thrust-blocks.

The speed of the turbines is controlled by a cylindrical casing surrounding each wheel, and capable of being moved up and down as occasion requires, forming a valve to throttle the discharge on the outside of the wheel. The wheels are stopped by closing the gates between the top of the water column and the intake canal. Each guide-wheel has thirty-six buckets, whereas the turbine-wheel has thirty-two, and the buckets are thicker in section at the centre. The turbine-wheel sections are in single castings, with both rims and buckets in one piece of bronze of the same quality as that usually adopted for the propeller-blades of steamships.

Each one of these turbines will discharge 430 cubic feet of water per second, and works under a head of 136 feet from the upper surface of the water to the central plane between the upper and lower wheels. They are designed to revolve at 250 revolutions per minute, and to then develop 5,000 horse-power with an efficiency of 75 per cent. These wheels were designed by Messrs. Faesch and Piccard, of Geneva, Switzerland, and were constructed by the I. P. Morris Company, of Philadelphia, Pennsylvania. The assemblage and erection of this machinery was carried out under the direction of Mr. De Courcy May. The first, or preliminary installation, as it is called, is of three of these turbines with their superimposed dynamos, of which two are now in successful operation.

The Vertical Shafts.—Each shaft is a steel tube, built of sections about 38 inches in external diameter, except at the three points

where it is received by the bearing. The journal is there made solid, and is 11 inches in diameter. The weight of the vertical shaft, 166 feet in length, with the portions of the dynamo that are attached to and revolve with it, is 152,000 lbs. A water-cooled thrust-bearing, to resist thrust in both vertical directions, is provided at the upper end of the main shaft to receive the resultant pressure along the shaft, which varies with the speed of the wheel, as well as to keep the apparatus in a fixed position in a vertical direction. When the wheels are running at full speed, a freer outlet is afforded the water. This leads to the slight diminution in the vertical component of the pressure on the upper turbine-wheel as already noticed. The thrust-bearing at the turbines consists of a series of steel rings on the main shaft, fitting into corresponding grooves in a babbit metal collar, secured to the framework of the foundation.

The Power-House.—The power-house is built of Queenston limestone, is 195 feet long, and is capable of extension for a further length of 300 feet; and its side walls are 40 feet in height from the floor-level. It has a steel-trussed roof with a clear span between the side walls of 61 feet. The building consists of a steel skeleton frame, and stone walls, constructed independently of the framework and designed to carry only their own superincumbent weight, the weight of the roof trusses being carried by steel columns. The loads due to the 50-ton electric travelling-crane are also carried by steel columns. This crane commands the whole floor of the house and has unusually long steel wire-rope connections capable of reaching to the bottom of the turbine-pit. The power-house was designed by Mr. Stanford White, to accommodate ten turbines. The present house is only built of sufficient length to contain four turbines, the end of the building being closed for the present by a wooden partition.

The Dynamos.—The dynamos, *Figs. 3* and *4*, are about 13 feet 6 inches both in height and in diameter, and are compact machines. They are arranged to give two equal alternating currents differing in phase by an angle of 90°, each current having the comparatively low frequency of twenty-five complete cycles per second. The wave phases give slightly flattened sinusoidal curves. The two circuits are quite distinct one from the other; the difference of potential amounts to 2,400 volts in each circuit at the terminals, but the machines may be worked sometimes at as low a difference as 2,100 volts. The normal speed is 250 revolutions per minute, and they have been designed to work continuously at full load without their temperature rising 40° C. above that of the atmo-

sphere. They belong to the type in which the field magnets revolve, whilst the armature coils are fixed, a mode of construction that offers much advantage when the machine is of large size. The frame of each machine consists of a cylindrical casting resting on a circular foundation plate, which is in turn supported by heavy masonry arches built over the turbine-pit. The frame has external flanges by which the armature is retained in position, and its inner surface has inverted conical seatings that receive the four-armed castings carrying two bearings for the upper vertical shaft situated in the third gallery above the turbines. These bearings are bushed with babbit metal, and spiral grooves are provided through which a current of oil is caused to circulate under pressure, arrangements being also made by which the bushes can be cooled in case of need by the circulation of a current of water through exterior channels.

On the top of the shaft a six-ribbed steel casting or "spider" is keyed, and this carries a massive nickel steel ring 11 feet 6 inches in diameter. This ring with its attachments weighs 80,000 lbs., and serves as a fly-wheel; it is $4\frac{7}{8}$ inches thick, and 51 inches wide. The material has an ultimate tensile strength of 80,000 lbs. per square inch, with an elastic limit of 48,000 lbs. per square inch, and, at its normal speed of working, 250 revolutions per minute, its outside surface travels at the rate of about 2 miles per minute. The rings of all the machines were made at the Bethlehem Iron Works, Pennsylvania, from solid cylindrical ingots, which, after being forged under the steam-hammer, were bored and then forged into shape under an hydraulic press. Nickel steel is particularly suited for this purpose, not only on account of its great strength and toughness, but also on account of its electrical properties. Attached to the inner surface of this cylinder are twelve open-hearth steel pole-pieces, each one being secured by six iron bolts $1\frac{1}{2}$ inch in diameter. These pole-pieces are wound with two copper bars, air insulated, and covered externally with brass casings. The weight of each pole-piece with its bobbin is 2,800 lbs. They are excited by a continuous current obtained from the main alternating ones by 200-kilowatt rotary transformers placed in the power-house; the energy so employed is equal to 10 HP., or 0·2 per cent. of the main output. This exciting current, a direct one, at a potential of 175 volts, is carried to the field-magnets from the transformer through covered conduits beneath the level of the floor, through the foundation and up one of the hollow iron columns that supports the bridge across the top of the machine, along this bridge and to the revolving shaft, by two fixed copper

brushes that rub on two hardened copper rings, suitably insulated and fixed on the top of the shaft. These rings are directly connected with the windings.

The core of the armature is built up on the cylindrical framing of the machine already referred to, and lies wholly within the revolving system of field-magnets. It is formed of thin plates of soft iron, the surfaces of which are oxidized, and the whole mass is held together by nickel steel bolts. In the outer surface of this armature, 187 vertical rectangular recesses are formed to receive the armature winding. This latter consists of copper bars $\frac{1}{2}$ inch by $1\frac{1}{4}$ inch in cross-section, two bars being placed in each recess. The insulation is of mica. It will thus be seen that the winding is wholly on the outside, enabling ready access to be obtained in case of need. The bars are connected in series so as to give two independent circuits, and separate cables connect each circuit with the switch-board.

The design of the dynamos with fixed armatures allows the coils to be more securely wound and to be free from the mechanical stresses induced by centrifugal action. Currents can also be taken from the machines without the intervention of cumbersome brush-holders, or of commutators, which, with very large currents, involve problems of serious difficulty.

By means of the field-magnets on a metal ring with their poles projecting radially inward and weighing about 70,000 lbs., a fly-wheel is obtained, and the magnetic stress between the fields and the armature acts as a partial counterbalance to the centrifugal force. A further advantage, in the design adopted, is that space is afforded to the workmen in which to attend to the bearings. In the tests of the first machine a man was stationed inside the armature space during the running of the machine, with telephone connections to the office outside by which to communicate the conditions of the bearings. There is, indeed, a clear space, 5 feet in diameter, in the middle of the machines. This feature of the design is of great advantage in allowing the replacement, by the aid of the electric cranes, of portions of the turbine shaft or other machinery beneath the dynamos whenever required, without the necessity of dismantling the dynamos more than by the removal of the field-magnet system and shaft, which is very readily performed. In these dynamos the centrifugal tendency of no part of the revolving system is restrained by bolts or keys—an important advantage. The formula used in designing the parts of the revolving machinery was that the sum of the weight of each part, multiplied by the square of its velocity in feet per second, should

equal 1,100,000,000. Great care was exercised in balancing the revolving parts, so that the machinery would run true at the highest speeds it would ever be subjected to in practice.

When the first dynamo was put in operation at full speed it was found that the moving parts continued to revolve for thirty-nine minutes by their own inertia. As it was considered important to be able to stop the machine quickly, the ingenious device was adopted of reversing the fields by means of a current in the opposite direction, in this way putting on a load which served as an electrical brake, by which the revolving system can be stopped almost instantly. It has been found that the power required to overcome friction and drive the motor and generator without load is 76 HP.

The Niagara Falls Power Company, which has a charter from the State of New York, constituted, in 1889, a subsidiary company, the Cataract Construction Company, by whom the plans for the utilization of Niagara have been decided on and carried out. Mr. E. D. Adams is the President of this company, and Mr. William B. Rankine is the Secretary. In 1890 this company invited various firms in America and Europe to submit plans for the hydraulic utilization of the power and its electrical distribution. A sum of $22,000 was set apart to be awarded to competitors who furnished plans in accordance with the invitation. To decide on the merits of these plans a Commission was formed, consisting of Sir William Thomson (now Lord Kelvin) as Chairman, with Dr. Coleman Sellers, of Philadelphia, Lieut.-Col. Theodore Turrettini, of Geneva, Switzerland, and Professor E. Mascart, of the College of France, as members, and Professor W. C. Unwin, F.R.S., as Secretary. Subsequently revised plans for the turbines were obtained from two of the competitors, and one of these was selected, and has been carried out in the installation at Niagara. The dynamos are of the type and general construction proposed by Professor George Forbes and the engineers of the Cataract Construction Company, to whom the installation of the general plant for the Niagara Falls Power Company was entrusted.

The general design and details of the dynamos have been worked out with great care, under the direction of Mr. Albert Schmid, the general superintendent of the Westinghouse Electric and Manufacturing Company, the firm by whom they were built. The efficiency of these large dynamos is remarkable, and Mr. L. B. Stillwell, the Chief Electrical Engineer of the Westinghouse Company, under whose immediate supervision the work was done, has furnished the Author with the following information bearing upon this point :—" When operating with a difference of potential of

2,100 volts at the alternating current terminals, the total electric and magnetic losses will not exceed 2 per cent. The mechanical losses—that is, losses in dynamo bearings and air friction—will be less than 1 per cent., and will probably approximate three-quarters of 1 per cent. The net efficiency of the generator will therefore exceed 97 per cent. and will probably very closely approximate 97¼ per cent." As an example of the small loss due to mechanical friction, the occasion on which the dynamo ran for more than half an hour after power had ceased to be applied may here be again mentioned.

The circuits of the machines already erected are carried independently in cables to the stationary transformers of the Pittsburgh Reduction Company. The commutation of the two currents in quarter-phase difference can be more easily arranged for electro-metallurgical use than would be the case with a single current, and it must be remembered that the two circuits may also be kept perfectly independent and used to supply separate motors. The low frequency of 3,000 alternations per minute, adopted as the one best suited to the requirements of the installation, has occasioned increased cost in the static transforming machinery; but as the unit for the supply of power will always be large, the disadvantage is more than balanced by the increased efficiency of the low-frequency currents when employed for motors, by the reduced cost of the rotary transformers, and by a decrease in the difficulty of dealing with insulation and eddy-currents. It is easier also to run the dynamos in parallel.

It is the practice to run dynamos in parallel, and to have them interchangeable so that the machines can relieve one another. This will be necessary in order to insure continuity in the supply of energy to the electro-metallurgical works. The low frequency of the current at this installation would occasion flickering, if used direct for arc or incandescent lamps, but will not affect the electro-metallurgical work, the alternating current being first transformed to a continuous one by the motor generators or rotary transformers. It is possible to use the current as now supplied to the plant of the Pittsburgh Reduction Company in any required manner, either by the employment of synchronizing alternating motors without transformers, or by direct current motors or rotating phase-induction motors. The conductors from the dynamos are all placed in conduits under the floor of the power-house.

The Paper is accompanied by numerous drawings and photographs, from which the *Figs.* in the text have been prepared.

APPENDIX.

Ores of Aluminium.

The Bauxites.—The double- and triple-hydrated oxides, forming the mineral bauxite, are the cheapest and best ores of aluminium. Bauxite consists of sesqui-oxide of aluminium, together with from two to three molecules of water of hydration ($Al_2O_32H_2O$ to $Al_2O_33H_2O$), which would yield :—

	Triple Hydrate.	Double Hydrate.
	Per Cent.	Per Cent.
Alumina	65·61	73·9
Water of hydration . .	34·39	26·1

The best varieties, as found in nature, are contaminated with between 1 per cent. and 5 per cent. of titanic acid and silica, with hydrated sesqui-oxide of iron ($Fe_2O_33H_2O$) replacing the hydrated alumina in varying proportions; the red-coloured varieties of the mineral often having as much as 15 per cent. or 18 per cent. of the sesqui-oxide of iron, and sometimes with as little silica as 1 per cent. up to 3 or 4 per cent.; while the white-coloured mineral often has between 10 per cent. and 20 per cent. of silica in it, and the correspondingly low amounts of from 1 per cent. to 3 per cent. of oxide of iron. These latter minerals, high in silica, but low in oxide of iron, are often still rich in alumina, and seem to have a part of the water of hydration replaced by silica; many specimens have only between 18 per cent. and 20 per cent. of water of hydration. These ores are especially adapted for treatment by sulphuric acid of 42° Beaumé for the preparation of sulphate of alumina. The bauxites almost always contain between 1 per cent. and 5 per cent. of titanic acid, and often a small amount of vanadium.

The French bauxites, which were the first discovered and mined, have the following composition :—

Hydrargyllite.

Red Bauxites of the Var, with Aluminate of Iron.		White Bauxites of Villeveyrac Hérault, with Basic Silicate of Alumina.	
	Per Cent.		Per Cent.
Alumina	60	Alumina	60
Silica, up to	3	Silica, up to	20
Ferric oxide, up to	18	Ferric oxide, up to	3

Besides these ores, there are large quantities of bauxite minerals ranging from maximum-silicious bauxites, which are basic silicates of alumina, or "fat" clays, to maximum-ferruginous bauxites, which are aluminates of iron. The French

ores are found in the Southern Departments of Var, Bouches du Rhone, Alpes Maritimes, Hérault, and Ariège. They are of massive conglomerate or oolitic structure. The Irish, Styrian, and Austrian bauxites are denser and more earthy minerals. As a rule they carry somewhat higher proportions of silica, but are in other respects similar minerals to the French product. European bauxites are said to occur in the Tertiary and Jura-Triassic formations. Bauxite has been mined since 1872 in France, Messrs. Augé & Co., of Montpelier, being the largest miners and dealers in the mineral.

The bauxites of France are, according to M. Francis Laur, of the firm of Messrs. Augé & Co., a well-recognised authority in the matter,[1] probably residual deposits from the decay of basalt.

Messrs. George Blackwell and Alexander Sutherland have exploited the Irish bauxites upon the land of the Marquis of Downshire at Strain, near Ballyclare, Antrim. Most of the Irish bauxites contain as much as 12 per cent. of silica.

The American bauxites are found overlying the Knox dolomite rock, extending over a considerable area in a north-easterly and south-westerly direction through several countries in the north-west of Georgia and in the north-east of Alabama. The more plentiful ores in this district are similar to those found in Europe, and contain 10 per cent. to 20 per cent. of either oxide of iron or silica, with the usual amount (3 per cent. to 5 per cent.) of titanic acid common to all bauxites. There are, however, some large and valuable deposits of this mineral from which many thousands of tons of ore have already been extracted, containing less than 3 per cent. of silica and less than 1 per cent. of oxide of iron. The Pittsburgh Reduction Company draw their main supplies of alumina from these sources at the present time. The Georgia deposits were first exploited in 1887, but mining on an extensive scale in that State, as well as in Alabama, has only been developed within the last four years.

The Georgia and Alabama bauxite is found in pocket formations in a belt 30 miles wide and 75 miles long, in the Chattooga, Floyd, Polk and Bartow counties in Georgia; and in the Cherokee, Etowah, Calhoun and Cleburne counties in Alabama. These formations are somewhat similar in character to those noticed in places where manganese and limonite iron ores occur in the Southern Appalachian region. The bauxite is not found in continuous beds or in veins, but in pockets having well-defined outlines and containing compact masses of ore amounting to many thousands of tons each.

The supply of bauxite in Georgia and Alabama is very large, enough without doubt to meet the demand for many years. The ore-bearing formations are surrounded by rocks of the older Cambrian formation, represented by the Rome sandstones below them, and by the Connasauga aluminous shales above them. In the southern portion of the region, the Rome sandstones are replaced by the Weisner quartzite of which both the Weisner and Indian Mountains are composed. Above the Connasauga shale is the Knox dolomite, which is the most uniform and persistent formation of the Southern Appalachian region. The Knox dolomite is of the Upper Cambrian and Lower Silurian period; fossils are almost entirely absent from it; it has a thickness of between 3,000 feet and 4,000 feet. This dolomite is a grey semi-crystalline carbonate of lime and magnesia, containing much silicious matter, which by its disintegration has usually left a heavy residual mantle covering all the outcrops of the formation. The bauxite, as well as the limonite deposits of this portion of Georgia and Alabama, are found associated with the residual materials of this mantle, which is composed

[1] See Paper by Mr. F. Laur on Bauxite, Transactions of the American Institute of Mining Engineers, vol. xxiv., 1894, p. 234.

principally of ferruginous clay. The mantle usually has a depth of between 50 feet and 100 feet, and is remarkable for the large quantities of chert that it contains, both in nodules and in beds. The chert is a dull-coloured subtranslucent and somewhat brittle and impure variety of chalcedony or cryptocrystalline quartz. Immediately above the Knox dolomite the succession of rocks is broken, and the Chickamauga limestone, and, higher still, the Rockmark slates are found. The geological structure of the region is exceptionally complicated, and exhibits many folds and faults.

The north-western limit of the ore-bearing belt is a line of Rome sandstone hills, dipping towards the south-east, and adjoining the Coosa-Oostanaula Valleys, from Calhoun, Georgia, to Mount Weisner. Massive beds of Cambrian quartzite are found upon the southern border of the region. The strata of the whole district exhibit the effects of great compression concentrated upon narrow belts between harder and more resistant rocks. This compression is shown by the existence of many geological faults, among the more important being the Coosa thrust fault, along the line of which the bauxite deposits have been found most abundantly. Dr. C. Willard Hayes, of the United States Geological Survey, who has given the subject careful study, reports that the region has from very early geological time been the seat of oreoganic activity.

The distinctness of the bauxite deposits from the surrounding residual clay in this district contrasts remarkably with what is seen in other deposits of bauxite, which appear to be the residue of decayed rock. The Georgia-Alabama bauxite indeed shows distinct stratification, the material being found in layers of different colours, although no trace of bedding is discernible in the surrounding clay. These beds have usually a steep dip, which exceeds the slope of the surface of the uneven land in which the ore bodies are mined.

The ore varies greatly in appearance; a large portion of it has a very characteristic pisolitic structure of a grey colour, the individual granules usually ranging in size from $\frac{1}{10}$ inch to 3 inches in diameter, the most common size being about $\frac{1}{2}$ inch diameter. The Author has one such pisolite which is more than 2 feet in diameter. In some beds the ore is found in large concretionary lumps of oolitic structure, weighing $\frac{1}{4}$ lb. to 10 lbs. each. This ore is commonly called "donic." Beds of yellow, grey, red, and chocolate-coloured ore of fine-grained texture often alternate with those of pisolitic ore. This fine material usually contains more silicious matter in the form of kaolin than is found in the harder portion of the mineral. The presence of the sesqui-oxide of iron is the chief reason for the varying colour of the material, which runs from a light salmon and grey to dark red, although some of the bauxite also contains organic colouring matter. Some of the material is soft and even plastic as it is mined, while some of the dark-coloured mineral is nearly as hard as quartz. There are some beautifully violet-coloured manganiferous bauxites amongst those found in Georgia; but so far, no varieties have come under the Author's notice containing further metallic elements as impurity. If such minerals, however, are found, they may prove to be of commercial value, as affording a ready means by which aluminium alloys could be produced when a material harder than pure aluminium is needed.

Mr. Francis Laur considers the bauxites to be natural pigments or inorganic "lakes," and that they are natural bi-hydrates of alumina or hydrargyllites with about 27 per cent. of water. While most of the bauxites of Southern France and of Arkansas, Colorado, and New Mexico of the United States undoubtedly have this amount of water of hydration, yet there are many (in fact, most of the pure ores of Georgia and Alabama) which have more

than 34 per cent. of water of hydration, which would make them triple hydrates.

When the water of hydration is below 31 per cent. in the greyish and white-coloured minerals, it is found in the Georgia and Alabama bauxite that the silica is proportionately higher and has replaced a portion of the hydrated mineral. A bauxite with only 27 per cent. of water of hydration from this region will almost certainly contain as much as 8 per cent. of silica. The bauxites of Georgia and Alabama not only seem to have a different amount of water of hydration, but also appear to differ in their origin from those of France and the Western districts of the United States, where the bauxites are residual deposits from the decay of basalts, granites, &c., and contain remains of the constituent minerals of the parent rock, as well as traces of the original rock structure, the ore being disseminated throughout the eruptive mass.

No eruptive rocks are found in the vicinity of the bauxites of Georgia and Alabama, nor are there any rocks in this region which by weathering could yield bauxites as a residual product, as has been pointed out by Dr. Hayes, of the U.S. Geological Survey. He considers that thermal springs must have been the agent by which the mineral was carried to the surface from the underlying shales in some soluble form through the intermediate fractured strata, being subsequently precipitated where it is now found. He suggests that the water, first heated and containing much ferrous and aluminous sulphate, became highly charged with lime in passing through the Knox dolomite; and that a reaction of calcium carbonate upon aluminium sulphate took place, causing a gelatinous or flocculent precipitate of aluminium hydroxide, the basic sulphates remaining in solution. This action may have taken place at great depth, and the resulting precipitated alumina may in some cases have been brought to its place of deposit in suspension by the water. This explanation accords with the peculiar physical structure and methods of bedding of the bauxites observed in the Georgia-Alabama district.

The Arkansas deposits of bauxite occur as regularly stratified beds in rocks of tertiary origin, near their places of contact with eruptive syenites or hornblende granites. Prof. J. G. Branner, of the Arkansas State Geological Survey, states that the bauxites of the State are formed from these granites. In this opinion Dr. Hayes, of the United States Geological Survey, concurs. There are two theories as to the causes of their formation; one is that these bauxites are sedimentary deposits from mineral springs, while the other supposes the bauxite to be due to the double decomposition of chlorides of alumina and iron in contact with carbonates of magnesia and calcium. The bauxites of Arkansas occur in positions at between 250 and 300 feet above sea-level. As a rule they have no covering, the overlying beds having been removed by erosion, which has removed part of the bauxite in some cases. The deposits lie high enough above the natural level of the country to be readily and economically quarried, and are in the vicinity of Little Rock, Pulaski Co., and near Benton, Saline Co.; but the Arkansas ores have not yet been mined in a systematic manner.

Useful varieties of bauxites are found in Asia Minor and in South America.

Beyond its use as a source of alumina, bauxite is largely used for the manufacture of alum, and in setting the "size" or colour in the process of paper-making and in dyeing. It has further uses as a basic furnace-lining and as a pigment for the bottoms of boats and for other marine work.

Gibbsite.—Gibbsite, the stalactitic modification of the triple hydrate of

aluminium ($Al_2O_3 3H_2O$), containing 65·4 per cent. alumina and 34·6 per cent. water of hydration, which occurs in the purest beds of bauxite, has a specific gravity of 2·4, and is a purer mineral, freer from oxide of iron, silica and titanic acid, than is bauxite. Unfortunately, it has not been found in very large masses, although much of the better quality of bauxite found in Georgia contains a considerable quantity of gibbsite.

Native Sulphates of Alumina.—Alunogen, or aluminite (sulphate of alumina), and bauxites are also found in strata of volcanic origin in a district upon the Upper Gila River, about 40 miles north of Silver City, New Mexico, U.S.A., the adjacent rocks having been originally highly basic—volcanic porphyries and basalts accumulated in massive beds of brecciated fragments. These rocks have been altered and changed by solfataric action, or by the decomposition of disseminated pyrites, which has led to the occurrence of alunogen in outer crusts and layers, with bauxite beneath in the residual material. They have, in addition, been largely deprived of their silica and alkalies by acid solutions percolating through them. There is another large bed of this native sulphate of alumina, $Al_2(SO_4)_3 9H_2O$ (probably with residual bauxite under it), in Purgatory Valley, 12 miles east of Trinidad, Colorado. This deposit of sulphate of alumina contains about 30 per cent. of alumina in a condition suitable for cheap purification. The difficulties and expense of transport, however, render the New Mexico and Colorado bauxite and alunogen at present commercially unavailable.

Clays as Ores of Aluminium.—The clays vary from tribasic silicates of alumina to pentacid silicates, minerals with at most 65 per cent. of alumina and 35 per cent. of silica, while the more common varieties contain 50 per cent. to 70 per cent. of silica and only 35 per cent. to 50 per cent. of alumina. Pure kaolin contains 39 per cent. of alumina, corresponding with about 20 per cent. aluminium with 40 per cent. of silica and 14 per cent. of water. Now, as silica is much easier of reduction than alumina by all the methods so far used for the production of aluminium, this large amount of silica must be separated from the alumina before the reduction is commenced; otherwise much of the energy and of chemicals used in the reduction will be expended in the reduction of a troublesome impurity. The value of clay, therefore, as an ore of aluminium is small in comparison with that of the richer and purer hydrated oxides of aluminium, which have only small amounts of iron and silica to be removed before they are submitted to the reducing operation.

Pure bauxite ores can be delivered in Pittsburgh, Pennsylvania, at a cost of £1 10s. per ton at present. There seems to be only one method by which "fat" clays like kaolin may be used as aluminum ores, and that is treatment by cold concentrated sulphuric acid. This dissolves the alumina out of most clays, leaving the insoluble silica behind. The same reaction takes place, under favourable conditions, when mixtures of sulphates of the alkalies and alkaline earths with clays are heated and the mass is treated with water. The alumina can be subsequently precipitated from the solution by the addition of an excess of an alkaline reagent. These methods have been the subject of experiment, but so far, alumina has not been produced from them cheaper than from bauxite.

Cryolite.—The mineral cryolite is still used as an ore of aluminium, and is the source of a considerable amount of alumina sold by the Pennsylvania Salt Manufacturing Company to the Pittsburgh Reduction Company. Cryolite is the double fluoride of aluminium and sodium, containing 40·25 per cent. aluminium fluoride and 59·75 per cent. sodium fluoride, and thus corresponds to the formula $Al_2 F_6 6 Na F$. It is a massive semi-transparent, white mineral, easily fusible, usually occurs granular or indistinctly crystalline, is cleavable, has a vitreous

lustre, and specific gravity of 2·95 and hardness of 3. The common impurities in cryolite are quartz, siderite, chalcopyrite and galena. This mineral would not seem to be particularly adapted for, or have much importance in the metallurgy of aluminium. It contains only 13 per cent. of aluminium with 32·8 per cent. of sodium and 54·2 per cent. of fluorine, and is only mined at Ivigtuk, on the West Coast of Greenland, in latitude 61° 13′, a distance of some 12 miles up the Arksuk Fiord. This place is, moreover, only accessible to navigation during the early and latter parts of the summer, on account of pack-ice and ice-bergs. Its chief importance is derived from the fact that, together with the more common and cheaper mineral, fluorspar, and an excess of alumina fluoride, it makes one of the best fluxes in which to dissolve the oxide of aluminium for the purpose of electrolysis. Although it is easy to manufacture the mineral artificially, yet large quantities of it are exported annually from Greenland, the chief American consumer being the Pennsylvania Salt Manufacturing Company. This Company uses the mineral as a source of pure soda suitable for making soap and the soda salts, as well as cryolite glass, alum, aluminium sulphate and alumina. The salts thus made from cryolite have a high reputation for purity.

It is probable that cryolite will not command so large a sale in the future as it has done in the past, since better methods for the purification of bauxite and the production of soda from salt by electrical means are being developed.

At Miask, in the Ural Mountains (which are prolific in minerals that are rare elsewhere), cryolite has been found; but, so far as is known to the Author, the mineral has not been commercially worked there.

The triple fluoride of aluminium, sodium, and magnesium, is found near the top of the South Cheyenne Mountain, in the vicinity of Colorado Springs, in Colorado. It has a composition of—

	Per cent.
Aluminium	13·61
Magnesium	8·91
Sodium	18·05
Silica	1·94
Fluorine	57·49
	100·00

This mineral dissolves alumina and performs the functions of cryolite in the electrolytic production of aluminium. It exists in several veins, 6 feet to 10 feet thick, in the granite which forms the mountains. As far as is known to the Author, there has not been any pure cryolite found on Pike's Peak, in El Paso County, Colorado.

Discussion.

Sir Benjamin Baker, K.C.M.G., President, said he was sorry that neither the Author nor any one representing him was present. The Paper had unavoidably been delayed for some time owing to the building operations, and had been in the hands of the Institution nearly twelve months. It contained a great deal about the Pittsburgh Reduction Company, and the members must have been struck with the great advantages that that company enjoyed. In one of their works on the banks of Niagara they were within half a mile of one of the greatest and cheapest sources of power in the world, which he believed was equivalent to the consumption of 200,000 tons of coal a day in power; and in the other case, on the banks of the Alleghany, they had the exceptional advantage of being able to get steam-coal slack at 2*s.* 8*d.* per ton, with automatic delivery and mechanical feeding. There was another branch of the Paper, which would perhaps have been fresher twelve months ago, relating to the wonderful works at Niagara. They had heard a great deal about them in popular magazines during the past year. Many engineers of all nationalities were invited to assist in the work, and he was glad to say that one of them, a member of the Institution and an honoured representative —Prof. Unwin—was present that evening, and the members would be glad to hear some remarks from him. He begged to propose a vote of thanks to the Author of the Paper. Sir Benjamin Baker.

Prof. W. C. Unwin thought that in much of the criticism of the Niagara works, the fact was overlooked that the problem there was in many respects unique. In the first place, if the works at Niagara were to succeed it must be mainly as a source of supply of power, not as a source of supply of electric light. Then it was unique because at that place one consideration which always governed ordinary hydraulic installations was absent. In ordinary hydraulic installations the water-supply was usually barely sufficient for the requirements; and economy of water, especially in times when the water-supply was scanty, was an absolute governing consideration in the design. At Niagara the water-supply was extraordinarily constant, and at all times enormously in excess of any possible requirements. The problem was again unique on account of the enormous scale on which the works had to be carried out. On a smaller scale, Prof. Unwin.

Prof. Unwin. those works would necessarily fail. It was only on the condition that they could be carried out on a very large scale, with the utilization of about 100,000 HP., that they could be a great commercial and financial success. These, however, were not the only points in which the problem was different from that with which engineers in connection with such matters had ordinarily to deal. Having to utilize something like 100,000 HP., it was necessarily a condition that the units of power should be very large. Before those works were established he did not think there was any turbine in the world which delivered more than about 1,000 HP. The single unit at the Niagara works was 5,000 HP., which meant the adoption of a turbine of quite exceptional dimensions. Looking at the drawings of the turbine, members would be somewhat surprised at the fact that the entire 5,000-HP. turbine with its regulating sluices was really a piece of pipe no larger than the supply-pipe of the turbine itself. The compactness of the turbines was extraordinary. He thought that no one who had not really tried to design a turbine using 25,000 cubic feet of water per minute could properly appreciate how extraordinarily compact those turbines were. He had tried the problem, and had failed to approach such compactness with other types of turbine. He was not particularly favourable to the type of turbine adopted, but so far it had perfectly answered its purpose. He had seen many designs made for those conditions, only one of which, that arrived at, after two or three trials, by one of the best makers in Europe, seemed to approach a successful solution. It was an axial-flow turbine of twin type. One peculiarity of the installation at Niagara was that instead of having a wheel-pit for each turbine, as would seem natural, there was a long wheel-pit in the earth 180 feet deep and as long as might be necessary for twenty turbines. It was not, however, yet complete. When the Commission for examining the project had sat in London it was much questioned whether the dynamos should be placed as they were above ground or in underground chambers. At first sight it would seem that excavation would be a great deal economised by placing dynamos and turbines in an underground chamber and merely taking the supply-pipes down to them. There were many objections to underground chambers—inaccessibility, damp, and various difficulties of that kind. Even if that plan of underground chambers were adopted, there would not be much excavation saved. It should be remembered that water had to be carried down to the turbine, and, calculating the area of the pits to take the water down, it would be found that whether there

was a wheel-slot or a separate pit for each supply-pipe there was not much difference in the amount of excavation. The wheel-slot was excavated with greater facility than a number of separate pits. Having necessarily placed the turbines at the bottom of the fall and having decided to place the dynamos at the top of the fall, the wheel-slot was almost a necessity. Dealing with units of that size, what perhaps at first sight was not obvious, proved to be true, that no method could be adopted of transmission from the turbine to the dynamo, except that by a direct shaft; no form of belting, wire-ropes or gearing used for smaller turbines could possibly be used when dealing with the unit of 5000 HP. at such speeds as were possible with dynamos of that size. Having a dynamo at the top of the slot and the turbine at the bottom with a great shaft between, what was to be done with the enormous weight on the footstep? That difficulty had been overcome by simply utilizing part of the water-pressure in the turbine to support nearly the whole of the weight of the vertical shaft and the weight of the field-magnets of the dynamo. In the Paper the over-balance of pressure was given as 3,500 lbs., but he believed that in most conditions it was less than that. There was only a small surplus of unbalanced force which had to be carried by a thrust-block near the dynamos. In many of the designs of turbines submitted for the Niagara installation, although balancing more or less of that kind was adopted, there was in many of them the defect that in the regulation of the turbine the amount of the balancing force was altered. That was the fatal defect in some of the designs for turbines. There were some designs which would work perfectly well if the balancing was quite perfect when the turbine was running at a full load, in which all the balancing effect of the water was altered when the turbine was running at light load. There was one other peculiarity in the installation. The dynamos required a constancy of speed greater than any turbine maker had hitherto had to deal with on a large scale. That had been overcome by the adoption of a remarkably ingenious form of relay-governor, in which there was an extremely sensitive governor with nothing more to do than to send a message to the relay to move the sluices a certain amount. When the sluices had been accordingly moved the relay waited to know whether the governor said, "go on" or "go back." In that way all possible hunting was prevented. He believed that the governor had been erected under a guarantee that if half the load was suddenly thrown off, the variation of the speed would not reach 2 per cent. So far the works had been started quite

Prof. Unwin.

Prof. Unwin. successfully. The tunnel was an extraordinarily large work of its kind for power installation. He thought it would be better made with a much flatter slope so as to be treated as a pipe discharging under water than as an open channel. The slope was, on his recommendation, somewhat lowered, but it appeared to him that the tunnel ought to be treated as a submerged pipe. He saw no objection to that except the difficulty of access, which might be overcome by proper arrangements. Something of the fall in that case would be saved. There was, however, such a surplus of power at Niagara, that that was not a governing consideration, and there was only a very small loss on the whole of the work. It might be known to some members of the Institution that there was a probability of works quite as large, under the same direction as the works on the American side being begun on the Canadian side. At any rate, it was very probable that in the course of a year or two works would be started on both sides of the Niagara Falls.

Mr. Parker. Mr. THOMAS PARKER observed that the Author had stated that a large continuous electric current was passed through the molten mass with a small difference of potential, and that the process was carried on in carbon-lined iron pots, placed in series, the anodes being of carbon and dipping into the bath. It was further stated that the voltage was about 2·8, and that the losses were very small. He should be glad if the Author would state the number of vessels used in which the solution was electrolysed, and the total voltage between the terminals of the series of cells, the ampere-meter readings, and weight of metal obtained in a given time. It was stated that the theoretical quantity of power used was 5 HP. per lb. of aluminium per hour. He should be glad to know the exact quantity of energy used. The density of the current, too, as it entered the bath from the carbon anodes was very important. If those quantities were correctly given the amount of energy used per lb. of aluminium obtained could be found, and it would assist in electrolysing the molten salts of various other metals. The figures given in the Paper as to the production of aluminium were not in accordance with his own experience. Aluminium was, no doubt, delivered to the kathode, and did not need to sink through the electrolyte in a finely divided condition. The theoretical quantity of carbon anodes necessary for the decomposition of the aluminium was given in the Paper as $\frac{3}{4}$ lb. of carbon per 1 lb. of aluminium. He thought, however, it could scarcely be stated. If the Author could obtain anodes which were not attacked, that quantity would be negligible.

Dr. Samuel Rideal, after examination of samples of aluminium produced by the different processes, considered the statement that, by the Hall process, metal had been obtained containing 99·93 per cent. of the metal, a very sanguine estimate of the purity of commercial aluminium. In fact, the aluminium produced by the present processes contained a variety of elements, some of which, no doubt, had a very deleterious influence upon its mechanical and physical properties. It would seem desirable that the influence of those minute quantities of foreign metals should be more carefully studied. Amongst those impurities, silicon, carbon, iron, copper, and traces of titanium would seem to be unavoidably present in all the processes now used; but with regard to such metals as sodium, and those of the alkaline earths like calcium, which might be produced when calcium fluoride was present in the molten bath, they might certainly be removed by some further improvements in the process. It was exceedingly difficult at present when using cryolite to ensure the entire absence of metallic sodium from the metal. With regard to the bauxites used, it was not generally known that the colour of bauxite was not measured necessarily by the amount of oxide of iron present. It was well known that many high-coloured bauxites contained practically no oxide of iron.[1] Dr. Rideal.

Mr. G. L. Addenbrooke remarked, with reference to the arrangement of the field-magnets of the dynamos outside the armature, so that the magnetic force between them tended to counteract the centrifugal force which caused the wheel to fly to pieces, that the attraction between the magnets and the armature amounted to about 30 lbs. to the square inch. The field-magnets revolved with a peripheral speed of 9,000 feet per minute, and the centrifugal stress amounted to about 15 tons to the square inch, so that the back pull of the armature approaching was, in comparison with it, infinitesimal. He believed the maximum magnetic attraction between the two surfaces in absolute contact was only about 150 lbs. per square inch; and as there was about $\frac{1}{4}$ inch clearance between the two he thought that it amounted to about 30 lbs. per square inch. Mr. Addenbrooke.

Aluminium had hitherto been chiefly manufactured at Neuhausen in Germany, at Pittsburgh in the United States, and at Froges in France. The power required for the extraction of the metal had been given[2] as 16 HP. hours to 1 lb. of aluminium, and he

[1] "Aluminium," by Mr. J. W. Richards, 2nd edition, pp. 48, 49.

[2] "Aluminium," by Mr. J. W. Richards. Sampson Low, Marston & Co., 1896, p. 393.

Mr. Addenbrooke.

believed that was the figure which had been worked upon at Neuhausen for some time past, but he had good authority for believing that the power had been considerably reduced. It was stated in the Paper to be about 5 HP., not including the amount required for heating of the bath, which depended on the radiation from it. It had been suggested that the baths might be heated by a coal-fire or otherwise, so that the electric current would only supply the heat required for the decomposition of the aluminium, but he did not think that had hitherto been put into practice. One of the great requisites was the purity of the alumina. At present nearly all the alumina of the requisite purity was made in Germany, and he understood that the Pittsburgh Reduction Company at one time imported it from that country, but probably they were now making it for themselves. The cost of the alumina was about $2\frac{1}{2}d.$ per lb., and nearly 50 per cent. of aluminium could be extracted from it, so that the cost of aluminium in the ore amounted to about $5d.$ per lb. It appeared from the Paper that 1 lb. of carbon was required, with various other things, and beyond that the only question was the electric current, which, he thought, should not amount to a very large figure; probably at Niagara it would be less than $2d.$ per lb. If the power required was taken as 12 or 14 HP.-hours, it would seem that if there was no great loss in the process, which the Author had not mentioned, supposing the aluminium to be manufactured on such a scale as at Pittsburgh, it ought to be produced and sold at less than $1s.$ per lb. As copper was 3·3 times as heavy as aluminium, $1s.$ per lb. about equalled the cost of copper for any purposes for which it might be required. The electrical conductivity was about 56 per cent. that of copper, and as it was only one-third of the weight, it was a better conductor than copper by weight in the ratio of 100 to 180. If its price fell to $1s.$ per lb. it might be useful for overhead conductors.

It was a pity that the Author had not stated the cost of producing the power at Pittsburgh, although he had given some data which enabled it to be inferred. In England coal could be procured in some colliery districts at the price mentioned by the Author, at $2s.$ $6d$ per ton. delivered to the boilers. If 1 electrical HP.-hour could be produced for 3 lbs. of coal, which he thought was practicable with large compound or triple-expansion engines working under the best conditions, 750 electrical HP.-hours would be obtained for $2s.$ $6d.$, or 25 HP.-hours for $1d.$ Not more than 12 HP.-hours were required for manufacturing 1 lb. of aluminium, therefore the cost of the current produced from coal in the

best possible manner would not amount to more than $\frac{1}{2}d.$ per lb. for the coal used. The cost of stoking the boilers would not add more than $\frac{1}{2}d.$ to the price per lb. of aluminium. For the manufacture of aluminium or the supply of electrical power for any other purpose in the coal districts, as was done at Niagara, the works could be placed on a site of comparatively small area in a centre of population where power could be readily supplied for other purposes, and the great outlay in works, such as was occasioned at Niagara, would not be required. There would not be so much capital lying idle, although the actual generating expenses might be greater. Therefore, when the cost of electrical HP. was so small, the fact of being in the centre of a population with railways, near large towns and so on, would outweigh the advantages which could be obtained from water-derived power in some cases, and it would be quite possible for engineers in future to install large power stations in coal districts, with small difference in the expense. Mr. Addenbrooke.

Mr. Bertram Blount remarked, as to the lower oxide of aluminium, which the Author stated had been produced, that although iron—the chemical congener of aluminium—formed ferrous oxide, FeO, aluminium, in spite of being similar in most respects to iron, had hitherto not yielded a corresponding oxide. The only oxide of which thoroughly reliable evidence had been obtained was the sesquioxide, Al_2O_3. The carbon anode when acted upon by the alumina forming a constituent of the bath subjected to electrolysis was undoubtedly burnt away, and the product formed was carbon monoxide. On such considerations, the amount of carbon mentioned by the Author, $\frac{2}{3}$ lb. per pound of aluminium produced, was doubtless reckoned. Some of the speakers, especially Mr. Parker, had demurred somewhat to that view, and seemed to think that it was possible to obtain greater economy of carbon, which was a matter of some importance, because of the high cost of electrode carbon. It might be thought that carbon could be saved by carrying its oxidation to a higher point, viz., to the formation of carbon dioxide, but this appeared to him scarcely practicable. Another matter might be mentioned in which greater explicitness of statement was desirable. It was known that in the different processes known as the Minet, Hall and Heroult, which were very intimately blended, success was only attained when the electrolyte was kept in fusion, not by externally applied heat, but by the heat generated by the passage of the current through the electrolyte. In the bath, *Fig. 1*, p. 213, no arrangement was shown for heating it externally, and the presumption was that the contents were kept Mr. Blount.

Mr. Blount. in a state of liquidity by the passage of the current. It would be interesting to have exact information on this point, because Dr. Borchers, a German technologist of high reputation and large experience in these matters, had shown from theoretical considerations, and indeed by actual experiment, that great difficulties would always be encountered by any process seeking to reduce alumina in which the zone of greatest temperature did not lie in the centre of the bath. The quality of commercial aluminium was undoubtedly largely governed by the impurities it contained. There were few commercial metals with which he was acquainted that were not under a similar disability. It had also been recently shown by Mr. Moissan that a predominating influence on the quality of aluminium was exercised by sodium, a hitherto unsuspected impurity. That metal, although electro-positive to aluminium, and therefore unlikely to be reduced in the electrolytic bath in which aluminium was being deposited, yet under the influence of the high current-density which was habitually and necessarily employed in the electrolysis of alumina dissolved in cryolite or some similar substance, made its appearance and contaminated the finished article. When sodium was present, the aluminium contained a metal which was electro-positive to it, and capable of being corroded more readily than the aluminium itself; there was no evidence at present to show that such impurity was not segregated in the mass, and might form active centres of corrosion. In the experience which had been obtained in several countries on the possibility of using aluminium for light military utensils, etc., where weight was of much more importance than cost, experiment had gone to show that local corrosion was one objection to their being taken into regular employment. The probable cause of that local corrosion was the segregated sodium, and until some means were found to prevent the occurrence of sodium in the finished material, corrosion of that kind would be liable to occur. Not only was the sodium itself liable to attack, but, in contact with any aqueous liquid, it yielded a solution of caustic soda, which in turn acted on the aluminium. There was thus a secondary reaction of a comparatively violent kind which carried on the process of destruction unlimitedly, and therefore a small impurity might be of serious importance. It behoved those interested in the wide use of aluminium to study the question closely, and to make sure that the production of the metal which they proposed to supply for all purposes where it would come into contact with corroding agencies might be so carried out as to free it from that defect. Although aluminium

had a lower specific gravity than the salts which formed the electrolytic bath when both were in the solid state, yet curiously enough in the molten state the conditions were precisely reversed. This fortunate circumstance had this practical bearing, that whereas, had aluminium a lower specific gravity than that of the molten electrolyte, the manufacturer would be confronted with the difficulty of aluminium collecting towards the anode and burning as fast as it was produced; yet under the actual conditions which obtained, it sank quietly to the bottom and could be run off and utilized. Mr. Blount.

Mr. Thomas Parker observed that he meant that the carbon took no active part in the reduction; it was simply attacked by the oxygen liberated in the process, and gave heat to the bath. He quite agreed that the sodium was reduced in consequence of the excessive current-density at the anodes. Mr. Parker.

Mr. Crawford Barlow had visited the works of the Niagara Falls Power Company in the summer of 1895, and had been impressed with the immense amount of water that was pouring down through the turbine-pit. The placing of the dynamos at the bottom would, therefore, be out of the question, as the damp would have prevented their working efficiently. Reference was made in the Paper to the effect of the difference of levels, caused in the Lakes and the Falls by the abstraction of this water, and also of the water of other power-works proposed to be erected on the Canadian side. It was estimated that the Chicago Canal would lower the level of Lake Michigan about 0·3 foot, and taking into consideration the results of all the abstractions of water for the other power-works, the total was estimated to be about 1 foot. He had good authority for stating that the annual variation of the Lakes between winter and summer was between 1¼ foot and 2 feet, and there was, in addition, a very large variation produced by natural causes—periodic variations, varying in period between five years and ten years. The amount of that variation was 5 feet, and the result arrived at was that the abstraction of water by the Canal—and it might also be said, with regard to these power-works—was practically *nil* as compared to the very great variations produced by natural causes. Mr. Barlow.

Mr. H. C. Jenkins remarked that further information as to the aluminous compound, to which the Author had early in the Paper referred, would be interesting. It was well known that Mr. H. St. Claire Deville many years ago sought long, but vainly, to find a series of aluminous compounds which at that time he thought existed; and reasoning from the analogy that aluminium Mr. Jenkins.

Mr. Jenkins. presents, in its chemical behaviour, to iron, he had thought there would be an easy way to reduce aluminium to a metallic state if he could start with an aluminous compound. He had been thrown back, however, upon the compounds in the higher state of oxidation, and those had been in use ever since.

He would ask the Author whether, in his later experience, he found the process absolutely quantitative, whether it was a true electrolytic one, as it was generally assumed to be. It appeared at first sight a perfect analogue of the reduction of sulphate of copper in a bath of water and sulphuric acid. There was a mixed bath of fluoride; alumina was dissolved in it, being added from time to time, and this was broken up and the aluminium obtained at the kathode and the oxygen at the anode. The statement had been made somewhat freely in the past that this was not quite the case, and that the full tale of aluminium which could have been expected was not obtained. The return was given by Fontaine as only between 50 per cent. and 80 per cent. with a very similar process, but probably with more experience of the process much higher figures had been obtained. Yet there was a doubt. Then, too, the oxygen was supposed to be given off at the anode in the form of carbon monoxide. Why should that be? If the oxygen were given off only in a nascent condition as from a true electrolytic process, why did it not on an elevation of the temperature of the bath give, as might be expected, CO_2? That would considerably reduce the consumption of carbon, and ought to do no harm. He thought that the working apartment, into which the Author allowed carbonic acid to escape in considerable quantities, would need efficient ventilation. The composition of the bath was stated in the Paper to be triple fluoride of aluminium, sodium, or potassium, and of calcium, but the proportions were not given. In making experiments some time ago he had found a triple fluoride of aluminium, sodium, and calcium, where each base had an equal number of molecules of fluoride, to be a very fluid bath indeed, satisfying some of the conditions required; and it was less dense than aluminium, so that the aluminium as it was reduced sank through it freely. It was quite mobile and easily melted. The exact composition of the mixture used by the Author was not stated, but Fontaine, in describing the whole process, gave, in addition to the proportions of cryolite and fluor-spar—the two minerals that made up the bath—about an equal amount of aluminium-fluoride, so that the bath described by Fontaine contained very much more aluminium-fluoride than the proportions just stated, and was, therefore, less likely to become clogged during

work. He had endeavoured to reduce the somewhat rare metal, glucinium, in the bath. Glucinium was a metal very similar to aluminium, and although it was reduced, he could not collect it readily. The glucinium had a density of only 2·07, and consequently floated up to the surface and was burned as fast as it formed. He was able subsequently, with the aid of the bath, to separate glucinium from alumina after the reduction of glucinia had been effected by heating it with metallic aluminium. It was important to remember a fact that the Author had pointed out, namely, that many other metals could be reduced in the same way as aluminium if it was profitable to do so. Mr. Jenkins.

The current-density was a most important factor to know when carrying on the process. The scale of his operations had not, however, been stated by the Author. It was almost suggested that the greater part of the 15,000 HP. was employed by the Pittsburgh Reduction Company, and there were varying statements as to the amount of power actually taken. In one report [1] it was stated to be 6,500 HP., in another [2] it was given as 2,000 HP., which appeared to be the more likely. It was also stated [2] that at the Pittsburgh Reduction Works a difference of potential at the constant-current dynamos of 160 volts was used. That value was, however, omitted from the Paper. It was known that the potential on the alternating low-potential main was 115 volts, but that of the continuous-current main was not given. He would assume that somewhat more than 2,000 HP. was taken, and that a continuous current of about 10,000 amperes at 160 volts was used. From the Paper it appeared that 1 cubic foot of the solvent employed would produce 1 lb. of aluminium per hour. It also appeared that 1,333 ampere-hours were required to produce it, assuming that the reduction was perfect and quantitative. All the baths were in series, so that 7½ cubic feet was the volume for each bath, and the dimensions about 1 foot 3 inches wide by 1 foot 3 inches deep and a little more than 5 feet long. The current-density on this data would be about 460 amperes per square foot at the kathode, but it was much greater at the anode—ten or fifteen times as great. That would produce 7½ lbs. per hour, or 180 lbs. per day. The difference of potentials of the bath was scarcely indicated. It must, however, be more than 2·8 volts, which was the difference of potentials necessary to break up alumina under those conditions. It was probably a difference of about 4 volts,

[1] "Mineral Industry," vol. ii. 1893, p. 7.
[2] *Cassier's Magazine*, Niagara Number, vol. viii. p. 336.

Mr. Jenkins. and about that which would break up the solvent itself. In describing the process, Mr. H. Fontaine [1] had given it as between 7 volts and 8 volts. Assuming that there were forty baths in the series, with a difference of potentials of 4 volts each, there would be a daily production of 7,200 lbs. from the whole plant, which agreed well with the estimates which had been given [2] as the proposed output. It also gave the production of a pound of aluminium with the expenditure of 6·6 E.HP.-hours. If the Author used more electrical energy than was assumed to be the case—more than 2,000 HP.—the calculation would give a greater density of the current in the bath. If it was assumed that he used 15,000 HP. when the bath was drawn to scale, the density would be about 800 amperes per square foot. But perhaps the Author would give the exact figures.

Mr. Head. Mr. JEREMIAH HEAD had visited the works of the Pittsburgh Reduction Company, and had seen the processes described. The results achieved seemed superior to any that had been previously obtained. The most striking point was the enormous power required to supply the current necessary for a comparatively small production, and also the fact that the material, the alumina, actually being decomposed, was apparently very pure and must have undergone certain preliminary processes before it could be brought into that state from natural products. It also appeared that the heat of the electric arc did not seem to be sufficient for its reduction without the addition of fluxes, the effect of which must be to render it reducible at a lower temperature than otherwise would be the case. The name of Sir Lowthian Bell ought to be mentioned in that discussion, seeing that there was no one in England who had devoted more time, attention and expense to obtaining the metal aluminium from its oxide than he had done, although he was not in the end successful, because of the great amount of material he found he had to treat in order to obtain a very small quantity of this metal. The superiority of the present process was at once shown by the cheapening of the product from about 6*s.* per lb. to less than 2*s.* per lb. He had visited the power-house at Niagara City, and had been impressed by the completeness of the arrangements, and the gigantic nature of the enterprise. The new works commenced by making the tunnel, the mouth of which was a little above the Niagara River, driving it inland a distance of between 1 and 2 miles, so as to be able to turn

[1] "Electrolyse," by Mr. H. Fontaine, Paris, 1892, p. 346.
[2] "Mineral Industry," vol. ii. 1893, p. 7.

into a "tail race," so to speak, whatever water was diverted at the top level from the rapids above Niagara, and make it operate turbines in its descent. Along the top of the cliff and not far from the mouth of the tunnel, were arranged a number of corn-mills and other old-fashioned factories, which equally used water diverted from the Rapids above the falls, which, after turning the water-wheels, or turbines, or whatever was used for obtaining power, was taken out through the cliff at a comparatively short distance below the upper surface. A number of these tail-races could be seen pouring out at 50 feet or 100 feet only, below the surface. That was all the power they took, although there was still a considerable distance down to the bottom that might have been utilized. It showed how wastefully water-power was applied in those times compared with the present, when works of the kind are scientifically considered and worked out. The planting of a factory for the production of aluminium at Niagara City was an enormous step in advance, inasmuch as the power was obtained from falling water, of which there was there an almost unlimited store. It was obtained cheaply compared to what would be the case if it had to be derived from a steam-engine or otherwise; not only was there this great factory, but there were others building which would be worked in the same way. The whole of the Niagara City power-house and everything connected with it was therefore a matter of extreme interest to engineers as being the pioneer, possibly, of many other manufacturing cities which might spring up in the future, and where manufacturing operations might be conducted. There was probably no place in the world where there was such an unlimited store of water-power as Niagara, but there were many other places where there was sufficient store to establish large factories, and perhaps even big manufacturing cities, so that the progress of these factories founded on water-power was of the greatest interest. In Norway and Sweden, where he had lately travelled a good deal, he had been impressed by the enormous quantity of water going to waste everywhere, and with the idea that much benefit might be obtained from those waterfalls if they could be only applied to useful purposes. Arising from these considerations was the very interesting one of the conveyance of this electrical power for great distances without undue loss. At Niagara it was not as yet contemplated to convey the power more than about 20 miles, but by means of alternating currents he supposed it could be carried to a very much greater distance. It would require to be conveyed between 500 miles and 1,000 miles if any of the principal waterfalls of Norway or Sweden were to be utilized in England. The inhabitants of those

Mr. Head.

Mr. Head. countries were exceedingly anxious that their power should be conveyed to England for manufacturing purposes, and, in fact, many of them distinctly believed it was only a question of time as to when it would be done, and since the installation of Niagara had been erected, it was said the waterfalls in Norway and Sweden had distinctly risen in value. He indulged the hope that, in the progress of electrical science, it might be possible to carry power to much greater distances for useful purposes than had as yet ever been contemplated.

Mr. De Segundo. Mr. E. C. De Segundo remarked that no figures as to the cost of the production of aluminium were given in the Paper, although, to engineers, such data were of the highest importance. A great deal had been promised; in fact, when he had visited the works, he had been told that the cost of production would be such as to enable aluminium to be sold at about 1*s.* per lb. That figure, he thought, had not been approached. He understood that aluminium could be obtained in this country at 1*s.* 7*d.* per lb. In regard to the cost of the electrical energy at Niagara, which must be a large factor in the production of aluminium, he believed that it would be possible to sell one Board of Trade unit, one kilowatt-hour, for about $\frac{1}{4}d.$ and make a considerable profit. If that could be achieved and the power could be transmitted to the Pittsburgh Reduction Company's factory at an efficient rate, no doubt a reduction in the price of 1*s.* 7*d.* per lb. in aluminium would eventually be arrived at. It was significant that the Pittsburgh Reduction Company found it advantageous to erect a plant at Niagara, although good coal was so cheap at Pittsburgh. The scheme of bringing electrical energy, or energy in any form, from Norway under the sea, which Mr. Head referred to as having been seriously mooted, was not an impossible one in itself, but he feared that directly any scheme of the kind was broached, the owners of the waterfalls began to think the waterfalls were very valuable, and a correspondingly high rent was demanded. After all, the cost at which water-power could be obtained was not the only factor in the total cost of the supply of energy. It was thought, for instance, with regard to electric generating-stations, that when coal was cheap the cost of electrical engines must decrease accordingly. It did nothing of the kind, because the cost of coal was by no means the only factor in the total cost of production of electrical energy. And similarly the cost of water-power was not the whole cost; not only the production of electricity but the price at which the electrical energy could be sold at the spot at which it was going to be consumed must be taken into account. One

Board of Trade unit might cost a quarter of a cent at Niagara, but if it cost a quarter of a dollar at New York, it might be better to produce it on the spot with coal. Mr. De Segundo.

Mr. A. Wollheim had looked in vain in the Paper for the actual cost of energy per horse-power at Niagara, and the cost of horse-power per annum under contract. There was a more serious aspect to the question of water-power in Sweden and Norway. As far as he knew, all the waterfalls had been engaged in 1895 by American and German speculators. There was no necessity for laying cables across the sea to England. These Norwegian and Swedish waterfalls were very peculiarly situated, being only a few miles from the sea. The freight to England would be very low, so that these Norwegian falls were on an entirely different basis to the Niagara Falls, which could not possibly have a bearing on the productions of the world on account of the great freights. As to the cost of the works at the turbines, he had been investigating this question for some time, and had found the Neuhausen works cost £2 10*s.* per horse-power per annum, or about 2*d.* per horse-power per twenty-four hours. At the Niagara works the cost was stated to be about $1\frac{1}{4}d.$ per horse-power for twenty-four hours. He could not compare steam-power with that last figure, and he did not think steam-power could be developed for less than £7 10*s.* per horse-power per annum, *i.e.*, 6*d.* per horse-power per twenty-four hours. Mr. Wollheim.

Mr. Hunt, in reply to the discussion, stated that the voltage of any given series of pots varied with their size and with the amount of electrolyte required to be traversed by the current; usually between 5 volts and 10 volts were required per pot. The problem of obtaining anodes which would not be corroded in the electrolytic operation, had been in the manufacture of aluminium, as in other similar electro-metallurgical or electro-chemical operations, a vexatious one. Iron, copper, or nickel anodes had been employed advantageously instead of carbon anodes when alloys with these metals had been desired; but their use was obviously precluded when pure aluminium was required. The common impurities in aluminium as made electrically in modern apparatus, were a small amount of iron and silicon in the ordinary combined form, as they existed usually in pig-iron, and a graphitoidal allotropic modification as carbon similarly existed in pig-iron. Attention had recently been called by Mr. Henri Moissan,[1] to the presence of Mr. Hunt.

[1] Comptes Rendus, vol. cxix. p. 12, and vol. cxxi. pp. 794 and 851, and *post*, pp. 519 and 520.

Mr. Hunt. carbon and sodium in commercial aluminium. Mr. Hunt had given special attention to the precautions necessary to preclude the presence of these impurities, as well as to the occurrence of occluded nitrogen in the metal. The chief points to be attained were that the metal was not heated much beyond its melting-point in the presence of carbon, to prevent the contamination with carbon and nitrogen, and, in the case of sodium, that the most advantageous mixtures of the fluoride salts were used, and that the supply of alumina should be so uniformly fed into the bath as to prevent the electromotive-force rising and thereby causing the reduction of the alkali metals from their fluoride salts. He had called attention in the Paper to the fact that the electrical resistance greatly increased when the proper supply of alumina dissolved in the bath was diminished. It was at this point that skilful working of the process was especially required. Improperly electrically-made aluminium containing sodium seggregated in the metal had given especially poor results in many cases, and had been the cause of many failures of the metal to withstand corrosion. Copper and nickel were impurities in much of the metal made by re-melting scrap, occasioned by the fact that they were intentionally used as hardeners in many instances. The presence of these impurities, as of titanium, tungsten, chromium, and similar metals, was not inherent to the process, however, but was due to such metals having been added as hardeners in previous operations. With the exception referred to, together with occluded gases, there were no other impurities in commercial aluminium as at present manufactured. The metal was being regularly made in commercial practice with over 99 per cent. of purity.

Much of the corrosion of aluminium, to which attention had been called, had been occasioned by galvanic action. Aluminium standing so high in the series of electro-positive metals, it was necessary to insulate it from the more common metals with which it would be most likely to come into contact in ordinary forms of construction, when wet or immersed, otherwise the corrosion, largely at the expense of the most electro-positive metal, the aluminium, took place.

He was not aware of the occurrence of many high-coloured bauxites containing practically no iron, referred to by Dr. Rideal. The deep red-coloured bauxites were all continually classed as containing high percentages of the sesqui-oxide of iron, the red bauxite of the Var, containing some 18 per cent. of oxide of iron, being a good illustration of the class. Organic matter gave considerable variegated colouring to some bauxites, but this had always been in connection with the colouring of a considerable

amount of oxide of iron, in all the varieties that had come within his experience. There were some bauxites occurring in the States of Georgia and Alabama, which contained considerable amounts of manganese and vanadium, which in their oxidized forms had changed the colour of the bauxites, but these ores as well carried much oxide of iron. Both silica and titanic acid (two of the most troublesome impurities) did not change the natural white or grey colour of the mineral. He therefore agreed that colour was not a true measure of the purity of a bauxite. Mr. Hunt.

If the entire energy of the electric current could be used in producing its electrolytic effect, larger outputs per unit of power expended would be produced. The trouble had hitherto been in the use of external heat with the process that pot or furnace-linings, which were heated on both sides, were rapidly burned or worn away, and made to leak the very permeating molten fluoride which they were required to retain. Again, in all the operations hitherto conducted on a large scale, the heat evolved by the current traversing the electrolyte had been amply sufficient for the metallurgical operations; and cooling, rather than heat-retaining devices, often had been resorted to. While externally-heated pots had been successfully used—especially in operations on a small scale, where the relative surface for radiation had been very large —they were not used in the commercial practice at Niagara.

The costs of anhydrous alumina, quoted at $2\frac{1}{2}d.$ per pound, were excessive. It had been selling at somewhat less than $1\frac{3}{4}d.$ per pound in the European markets for the same time, and it was being made at a considerably lower price in both the United States and in Germany for the manufacture of aluminium. As to the costs of manufacture of aluminium, the following estimate had been given by Prof. Roberts-Austen.[1]

	d.
Energy	1·1
Alumina	6·0
Labour and superintendence	1·5
Interest, repairs and maintenance	2·0
Chemical stores	1·0
Carbon electrodes	2·0
	13·6

Each of these items had been considerably decreased by all the manufacturers of aluminium during the past two years, especially

[1] Report of Committee on Utilization of Water-Power at Periyar Works. Selections from the Records of the Government of India, Public Works Department, No. ccxv., Enclosure No. 1, p. 20.

Mr. Hunt. the cost of the alumina, as was evident from the rapidly lowering selling price of aluminium within the same period. He agreed that factors of freight and conditions for economical manufacture would, in many cases, outweigh the advantages of the more economical water-powers. The results of the Pittsburgh Reduction Company as to the consumption of coal and natural gas at the Kensington Works, had been practically confirmed by experiments made by the National Transit Company of Pittsburgh.[1] Various quantities between 20 cubic feet were given for the equivalent of natural gas for 1 lb. of coal; the average being about 12 cubic feet in most of the tests made with pure natural gas unmixed with air.

Further data had been published regarding the lower oxide of aluminium,[2] considered to have been the formula of AlO. The specific gravity of solid aluminium was, as Mr. Blount had stated, less than that of the solid fluoride salt mixtures generally used, and the reverse condition, when the aluminium became relatively heavier, happily only occurred when the materials assumed the molten condition. As to the output of aluminium per pound of alumina added as an ore, in the regular practice of the Pittsburgh Reduction Company, where the monthly totals of weights of ore used and of metal produced were regularly compared, the output was always within 1 per cent. of the theoretical amount of aluminium added as alumina. Considering the small losses in dust, etc., inherent in the handling of the powdered alumina ore, the operation on a large scale was a practically quantitative one. There were no losses of aluminium, as in ordinary metallurgical operations, in the form of slag or by volatilization.

As to the atmosphere of the working-room in which the electrolytic operation was conducted being oppressive or poisonous on account of excess of carbonic acid or presence of carbonic oxide or of fluorine, when the operation was being conducted normally and regularly, absolutely no trouble was experienced by the workmen. The buildings should be constructed high on posts and good ventilation arrangements should be provided, and with skilful work no trouble on this account should be experienced. But with lack of regular and skilful working, the surrounding atmosphere would be found to have the property of etching everything with

[1] *American Manufacturer*, November 30th, 1894.

[2] The Berliner Berichte of the German Chemical Society, 1890, p. 772; also 'Aluminium,' by J. W. Richards, 3rd edition, pp. 229, 230. Dr. Clemens Winkler was the first to publish data regarding the separation of this interesting lower oxide of aluminium.

which it came into contact, including glass, as well as the mucous membranes of every person within range. Grass grew luxuriously and green around the aluminium plants of the Pittsburgh Reduction Company. On the other hand, when the fluoride salts, rather than entirely oxide of aluminium were electrolyzed, an aluminium plant was a healthy place to keep away from. Mr. Hunt.

As to the exact composition of the bath, a solution that had been used extensively was composed of 677 parts of aluminium fluoride, 251 parts of sodium fluoride, and 234 parts of calcium fluoride. He had been much interested in the account of Mr. Jenkins's operations in the electrolysis of glucinium. Similar efforts had been made, with lack of success, under the Author's supervision. The greatest trouble had been to obtain a glucinium salt without too great an expense that was free enough from silica for successful operations.

He was glad to add his tribute to that given by Mr. Jeremiah Head to Sir I. Lowthian Bell, who, with his brother, was certainly a pioneer in the production of commercial aluminium, not only in Great Britain, but in the world. Next in chronological order, after the works established in 1856, and finally moved to Salindres, near Paris, by Mr. H. St. Claire Deville, came the works in Battersea, near London, erected by Mr. C. H. Gerhart, in 1859, and in 1860 the works at Washington, near Newcastle-on-Tyne, were erected by Sir I. Lowthian Bell. At his works much of the aluminium of commerce had been produced from which the study of its properties had been made. Referring to the long-distance transmission of electrical power to which Mr. Head had called attention, the problem now seemed to depend upon the proper form of insulation of the conductors for the high-voltage currents that would require to be transmitted. The experiments at Niagara had shown that even the best forms of porcelain petticoat insulators were insufficient, under some conditions, to insulate a current at 50,000 volts pressure.

The cost of large quantities of power at Niagara was about the same as at Neuhausen, between £2 5*s*. and £2 10*s*. per horse-power per annum. His experience showed that steam-power could be produced at between £5 and £7 per horse-power per annum, under favourable conditions, in large quantities.

Since the Paper had been written the Pittsburgh Reduction Company had increased the size of their Upper Niagara Works, and the amount of power first taken had been more than doubled, each of the rotary converters having been enlarged from 400 kilowatts to 600 kilowatts capacity, additional machines being also used. A

Mr. Hunt. still larger block of power had been taken from the Niagara Falls Power and Manufacturing Company, who worked the surface canal, which directed a portion of the water of the upper Niagara River from its natural channel around the falls through the centre of the City of Niagara Falls, New York, to a basin on the high bank of the lower river, a short distance below the State reservation, *Fig. 7*. This canal was 4,400 feet long. Ground had first been broken in 1853, but it was not completed until 1861, the canal being about 36 feet wide and about 8 feet deep. Only about 7,000 horse-power was utilized from this canal, as only 50 feet or 60 feet of head had been attempted until within the past few years. In 1892 the Niagara Falls Hydraulic Power and Manufacturing Company commenced an enlargement of its canal. The plan adopted

Fig. 7.

Scale, 4,000 feet = 1 inch.

was to widen the original channel to 70 feet, and make the new portion 14 feet deep. The canal was cut through solid rock below the water-line. The power for driving the drills in this work had been obtained from an air-compressor driven by water-power from the station at the end of the canal, the air being conveyed along the line of the canal in pipes. Here was presented the curious spectacle of the canal furnishing power to dig itself deeper, a condition of affairs that would undoubtedly receive further application in the rock-cutting for the new wheel-pits soon to be placed by the Niagara Falls Power Company. The availability of large amounts of cheap power, the fruit of previous operations, would prove of great advantage and economy in future engineering work at Niagara. The enlargement of the canal had been excavated by dredges, and the flow of water through it was not interfered with.

This improvement was now completed, and the canal had a capacity of 5,200 cubic feet per second, giving a surplus of 70,000 HP. after supplying the old lessees with about 7,000 HP. Mr. Hunt.

The water from the canal flowed into a hydraulic basin parallel to and about 300 feet back from the edge of the high bank of the Niagara river on the New York side, about 2,300 feet below the American Falls. For the Lower Niagara Works of the Pittsburgh Reduction Company the water would be taken in an open canal to a forebay 30 feet wide and 22 feet deep at the extreme edge of the high bank. From this forebay a penstock 240 feet in length and 8 feet in diameter, built of riveted steel plates, conducted the water vertically down about 135 feet to the top of the sloping bank, and thence down the slope to the power-house on the lower bank. The power-house, 180 feet long and 100 feet wide, was built upon a level ledge of Medina sandstone, which was cleared of surface debris consisting of broken and disintegrated rock which had fallen from the bank during past ages and covered the red rock to a depth of between 10 feet and 70 feet, by means of a "giant" nozzle, the water for this hydraulic mining being furnished under the pressure of the fall from the basin on the high bank. Owing to the contraction of the channel of the river below, there was an extreme fluctuation in the level of the river water at the site of the power-house of the Lower Niagara Works of the Pittsburgh Reduction Company of about 30 feet, and it was liable to sudden changes, especially due to the wind. On this account the first floor of the power-house on which the wheels were placed was set about 16 feet above the ordinary level of the water of the river, which was above the highest recorded rise, the remaining part of the head being obtained by the use of draft tubes. At the same level, and adjacent, on the up-river side was the wood-pulp grinding mill of the Cliff Paper Company, who used two Leffel wheels of about 1,250 horse-power each, revolving at a speed of 225 revolutions per minute. Each wheel was equipped on either side with a set of stones for grinding wood-pulp. This plant had been in successful operation since 1892.

The water was conveyed from the bottom of the vertical penstock through a horizontal pipe 10 feet in diameter suspended over the tail-race. This conduit had walls $\frac{5}{16}$ inch thick and supplied, through 60-inch valves and the bottom of the wheel cases, the turbines, which were three in number, and were situated directly over the supply-pipe. These turbines took the water from below and discharged it through draft tubes running down on either side of the supply-pipe. The wheels had horizontal axes, and each

Mr. Hunt. furnished 1,900 HP. under a head of 205 feet, and all parts were designed to stand the pressures due to a head of 220 feet without undue strain. The ordinary head would be 210 feet, which was the highest under which water had ever been used to develop power in the quantity to be used in this plant. The wheel-cases were each supported on 20-inch steel beams weighing 80 lbs. per foot and 21 feet 6 inches in length. The wheels were driven at a speed of 300 revolutions per minute, and were guaranteed to show a useful effect of not less than 78 per cent. at any point between full and three-quarters load of water under any head between 205 feet and 220 feet, and running at a constant speed of 300 revolutions per minute. This useful effect was guaranteed to be not less than 60 per cent., under the same conditions, from three-quarters to one-half load of water. To each end of the water-wheel shafts would be coupled, by means of flexible couplings, a direct-current generator capable of developing 560 kilowatts of electrical energy at 280 volts. These generators were eight-pole shunt-wound direct-current dynamos running at a speed of 250 revolutions per minute. The electrical current was to be conveyed upon suitably-designed brackets attached to the penstock, on aluminium conductors of 28 square inches cross-sectional area, equivalent copper conductors having an area of 17½ square inches. The pure aluminium bars used as conductors had been proved by actual measurement to have 62 per cent. of conducting power as compared with pure copper. The Lower Niagara Pot-Room Plant of the Pittsburgh Reduction Company for manufacturing aluminium was situated on the high bank directly above the power-house and between the hydraulic basin and the edge of the cliff. In this way necessity for transforming the current was avoided, and simplicity of working was obtained. The plant would probably be in operation about the 1st of July, 1896, when it was expected that about 10,000 lbs. of aluminium would be manufactured per day.

The general design of the new power-house of the Pittsburgh Reduction Company was similar to that already in successful operation of the Cliff Paper Company in their wood-pulp grinding plant. The general arrangement of both these plants, taking the water over the bank at a velocity of about 6 feet or 7 feet per second into a larger trunk, diminishing the velocity to about 4 feet per second, and taking the water up into the bottom of the wheel-case so as to place the wheels, which had their bronze wheel-runners absolutely balanced, due to the equal discharge of water on each side, on the level of the floor of the station, was, in many respects, novel. The engineering work of both plants

of the Cliff Paper Company and the Lower Niagara Works of the Pittsburgh Reduction Company had been entirely conducted by the chief engineer of the Niagara Falls Hydraulic and Manufacturing Company, Mr. W. C. Johnson, with the exception of a small amount of engineering work in connection with some of the details which had been carried out together with the supervision of the work by the Author, as the President and General Manager of the Pittsburgh Reduction Company. Mr. Hunt.

Correspondence.

Dr. Coleman Sellers remarked that during the month of August, 1895, a test had been made of the 5,000-HP. turbines which were described as erected by the Cataract Construction Company for the Niagara Falls Power Company, and the results showed an efficiency of more than 80 per cent., which, it might be noted, was 5 per cent. in excess of the efficiency guaranteed by the designers of the wheels, Messrs. Faesch and Piccard of Geneva, Switzerland. The test of the governing machinery had also come well within the specified guarantee, namely, to control the speed within 4 per cent. if one-fourth of the whole load should be suddenly either taken off or applied. The results of the tests of No. 2 turbine were shown in the following Table, from which it would be seen how the speed was affected by the varying loads. On the 30th September, 1895, the turbine had been put in operation without load, the speed being 250 revolutions per minute. An electrical Dr. Sellers.

Tests of Governors of No. 2, 5,000 HP., Turbine of Niagara Falls Power Company.

Load at Start.	Change of Load.		Speed at Start.	Greatest Alteration of Speed resulting from Change of Load.		Uniform Speed after Change of Load.		Duration of Perturbation.
HP.	HP.	Per Cent.	Revs. per Minute.	Revs. per Minute.	Change Per Cent.	Revs. per Minute.	Change Per Cent.	Secs.
5,000	−1,300	− 26·00	245	253	+ 3·27	246	+0·40	6
3,700	+1,300	+ 35·25	248	240	+ 3·23	245	−1·19	11
5,000	−1,500	− 30·00	245	255	+ 4·08	248	+1·20	8
3,500	+1,500	+ 43·00	248	235	− 5·24	245	−1·19	12
5,000	−2,000	− 40·00	246	257	+ 4·47	249	+1·21	11
3,000	+2,000	+ 67·00	248	234	− 5·64	245	−1·19	14
5,000	−2,500	− 50·00	245	262	+ 6·94	250	+2·00	11
2,500	+2,500	+100·00	249	230	− 7·63	245	−2·00	16
5,000	−3,000	− 60·00	245	270	+10·20	250	+2·44	14
2,000	+3,000	+150·00	250	225	−10·00	245	−2·00	18
5,000	−3,500	− 70·00	244	272	+11·47	252	+3·28	16
1,500	+3,500	+233·00	247	225	− 8·90	245	−0·80	19

Dr. Sellers. load of 5,000 HP. was then applied suddenly, when the speed fell to 220 revolutions and returned to 245 revolutions in twenty seconds. Experiments had been also tried by throwing off the entire load, in one case over 5,000 HP., when the increase of speed was between 245 revolutions and 300 revolutions, the perturbations extending over a period of not more than twenty-seven seconds.[1] In view of the magnitude of the plant and the novelty of the problem presented to its engineers, the starting of the machinery at the outset had been attended with fewer difficulties than might have been anticipated. The only difficulty of note was that experienced in connection with the bearings of the water-wheel shaft. These bearings had been designed by the makers of the turbine and were of the usual construction of four-part boxes of phosphor-bronze, each part being set up by wedges with screw adjustment, and the thrust bearing being collared and running in a four-part collar thrust-box, also of phosphor-bronze, and arranged to be cooled by circulation of water and well lubricated. In view of the difficulty with these bearings, Messrs. Faesch and Piccard had finally decided to adopt in place of them bearings of the character which Dr. Sellers had so successfully applied to the dynamo. After these changes had been made, and all of the bearings lined with babbit metal, the turbines were again put in operation, and from the start had continued without interruption, the tendency to heat being entirely remedied. The friction in the vertical shaft was so slight that when the ring gates at the turbine were closed, leaving a space between the ring and gate of but $\frac{1}{16}$ inch in width, the wheel did not stop but continued to revolve on account of this slight leakage at the rate of 40 revolutions per minute, the normal speed being 250 revolutions per minute. In stopping the dynamo it was necessary to do so under a load to check the machinery until the speed was sufficiently low to permit a pneumatic brake to be applied to hold the shaft stationary after the load had been entirely thrown off, when the large sluice-gate could be closed, and the flow of water stopped. Reference was made in the Paper to the dynamos driven by these turbines, and to the part taken in their design by the engineers of the Cataract Construction Company. As the work of the Cataract Construction Company required in every detail the approval of the Niagara Power Company the matter was simplified by the existing arrangement, whereby he had held the position of President and Chief

[1] The results of these experiments would be given more fully in the Report which was to be issued by the Cataract Construction Company to show the character of the work it had executed and the results obtained.

Engineer of the Niagara Power Company. Thus, when the proposal of Prof. George Forbes for a dynamo with revolving field-magnet had been favourably considered by the Cataract Construction Company, the general design of the machine upon which tenders were subsequently asked had been prepared under the joint supervision of its proposer and himself. He had designed the shaft bearings and the parts of the machine upon which its mechanical efficiency depended. In submitting the design to the electrical companies for tenders for the construction of the dynamos, latitude had been given whereby the design could be modified in the light of their experience in order to secure guarantees as to the results to be obtained as if the machine had been wholly designed by the contractor. The Westinghouse Electric and Manufacturing Company, to whom the award had been made, while accepting the general mechanical features of the design, were thus permitted to modify the electrical conditions to accord with their system. No long-distance transmission from Niagara Falls had yet been attempted. The applications for power for utilization on the ground owned by the Company had been so numerous as to completely exhaust the output of two of the three turbines installed and encroach largely upon the capacity of the third, and under those circumstances the immediate extension of the plant was under consideration. It had been the intention of the Niagara Falls Power Company to transmit electrical power to manufacturers at a distance as well as in the immediate vicinity of the power-house, and to permit manufacturers who desired to control their own turbines to erect machinery on the land of the Company, and to furnish them with water from the canal system, with a connection from the manufacturers' wheels to the main tunnel. The only company which had availed itself of this arrangement was the Niagara Falls Paper Company, referred to by the Author. That company had been in successful operation for a number of years, and was reputed to be the largest establishment for the manufacture of paper in the United States. In referring to the power-house of the Niagara Falls Power Company, the Author alluded to the electric travelling-crane. This crane, of 50 tons capacity, was used for erecting the machinery of the power-house, and was designed and built by Messrs. William Sellers & Co., of Philadelphia, to meet the requirements of the specification, which called for a crane capable of a lift of 150 feet without tendency of the chain or rope to pile up upon the drums in winding, avoiding thereby any sudden shock from slipping of the chains or ropes in

Dr. Sellers.

Dr. Sellers. operation. The crane was driven by a 45-HP. electric motor placed on the platform of the bridge, the various speeds being controlled by friction-clutches and gearing. The operator was so placed that from his position on the crane he could see to the entire depth of the wheel-pit when the hatchways were open and the pit was illuminated. The crane had a supplementary hoisting device, by which the lift was increased to reach to the lowest depth of the wheel-pit for lifting lighter loads, and this device was so compactly arranged as to permit its movable sheaves to pass through the centre of the armature when the dynamo was partially dismantled, thus rendering it possible to lift sections of the water-wheel shaft vertically out of the bearings should there be occasion to remove them. The power of the motor might be utilized either for the maximum capacity of the crane or for the rapid lighter hoist, the latter having an exceedingly quick motion. The machinery was so arranged that the same friction-clutches which applied to one hoist also controlled the other, so that one set of handles applied to both without complication or uncertainty in use. The closing gates between the top of the water column and the intake-canal were situated close to the wall of the building next to the main canal, and the machinery that operated the sluice-gates was attached directly to the steel columns that supported the roof and travelling crane. These sluice-gates, 14 feet wide in the clear, opening to 12 feet in height from the bottom of the canal, were a modification of the Stoney sluice-gate, each gate having two lifting screws, placed as far apart as possible and pendant from a beam above. The nuts into which these screws engaged were attached to the top of the sluice-gate, the gearing being arranged so as to be driven either by hand or power. For the power motion a separate motor of 8 kilowatts capacity was attached to each gate, controlled by a rheostat and automatic stop-motion that cut off the current when the gate was either up or down. The gates worked so easily that one man only was required to raise them by hand with a pressure of 12 feet of water against them. These sluice-gates had been designed by himself, and he had aimed at having them occupy as small a space as possible in the building, and, by the use of quick pitch screws, obtaining a high efficiency in the power applied to operate them. The current-density used in local transmission was not as low as that stated by the Author, viz., 350 amperes per square inch. At present it was about 1,000 amperes per square inch, but additional conductivity could be added at any time to reduce the loss in the distributing circuits.

18 February, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The President announced that the Council had accepted with great pleasure, on behalf of the Institution, from Sir Robert Rawlinson, Past-President, a portrait of himself, painted by Mr. Phil Morris, A.R.A.; and from the Hon. R. C. Parsons a portrait of the late Mr. J. F. La Trobe Bateman, Past-President, painted by Mr. Clegg Wilkinson.

(*Paper No. 2925.*)

"The Electric Street-Railway System of Montreal, Canada."

By GRANVILLE CARLYLE CUNINGHAM, M. Inst. C.E.

ELECTRIC street-railway systems have developed rapidly in Canada and the United States, for whereas eight or ten years ago this application of electricity was but in the condition of an interesting experiment of doubtful value, it is now almost universally used. There is scarcely a town in America large enough to support a railway system but either uses electricity or contemplates at an early date transforming the old horse-traction system into one employing electricity. In the United States in 1888 there were about twenty electrical roads in operation, having a total of 80 miles of track, and working ninety motor-cars. Early in 1890 these numbers had increased to 1,670 miles of line and 2,650 motor-cars. But the latest figures obtainable show that there are now in the United States 10,363 miles of line, on which are worked over 40,000 motor-cars. While this has been the progress in the United States, Canada has not been slow to adopt a system that is manifestly so convenient for the public. Montreal, Toronto, Hamilton, Ottawa, Winnipeg, Brantford, Niagara Falls and other places, have their electric systems either complete or in process of construction.

Almost all the lines in the United States and Canada are con-

structed upon the overhead single trolley-wire system. On some 15 miles or 20 miles in the United States the storage battery is used, with dubious success, and there are a few miles of a conduit system in an experimental stage; but with these exceptions the overhead trolley-wire system is everywhere used. The generators producing the electricity are, in by far the greater number of cases, driven by steam-engines; but in some instances water is employed as the driving power. In Canada this is notably the case in two instances—at Niagara Falls and at Ottawa. At Niagara, by excavating a turbine-pit about 80 feet deep, and driving an outlet tunnel under the Falls, power is obtained from turbine-wheels to drive the generators and produce the electrical energy. At Ottawa the current of the Ottawa River is used to drive the turbines that actuate the generators, and from this source of power the street-railway system is worked, the cars being at the same time lighted and warmed by electricity. The power contained in the current of this river is now being electrically transformed into useful work, not only for street-cars, but for many other purposes; and light, heat, and motive-power for all needs in the town are produced from the transformed energy of the river, so that the town will soon be independent of fuel.

The City of Montreal, the commercial metropolis of Canada, lies upon the northern bank of the St. Lawrence River. Large ocean steamers of various lines ascend the river, and here receive and discharge cargo. Above the city the Lachine Rapids render further navigation of the river impossible for ocean vessels. The present population, inclusive of the immediate suburbs of Cote St. Antoine, St. Henri, St. Cunigonde, and Maisonneuve, which are all traversed by the Montreal street-railway system, is about 300,000, and is steadily growing. A map of the town and these suburbs, with the lines of the tramway system indicated, is shown in Fig. 1, Plate 6.

In 1892 the franchise under which the horse-tramway system was being operated terminated, and the City Council asked for offers for its renewal for a period of thirty years. The offer of the Montreal Street-Railway Company was ultimately accepted, and a renewal of the franchise was granted to it for that period dating from August, 1892. The chief conditions of this franchise are that within three years the whole system should be converted from a horse- to an electric-system; that it should in that time be considerably extended on routes laid down by the Council; that fares should not be higher than 5 cents ($2\frac{1}{2}d.$); that tickets should be sold at the rate of six for 25 cents ($1s.\ 0\frac{1}{2}d.$),

and, at certain hours for working men, at eight for 25 cents; that payment of one fare or one ticket should entitle the passenger to travel over the whole system, and to be transferred, without additional charge, from one route to another; and that the company should pay to the city annually 4 per cent. of its gross earnings. Under this contract, operations for reconstructing the system were commenced in July, 1892, and have since been pushed rapidly forward, so that now the transformation of the system has been completed. The horse-system comprised about 40 miles of line, but the completed system comprises 74 miles of single line laid on 41½ miles of streets. There is now running a daily service of 140 motor-cars, and about fifty trailing cars. The single overhead trolley-wire system is employed.

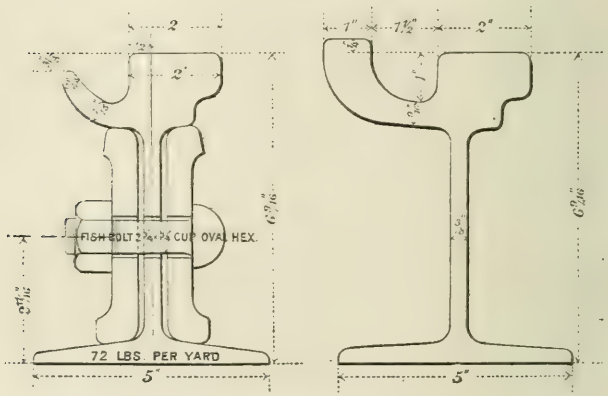
Gradients.—The gradients are in many cases very severe. On the streets running parallel to the River St. Lawrence they are easy, and such streets may be considered as practically level; but on streets at right-angles to this direction there is a continuous rise in most instances, and short sections have gradients of 1 in 10 (for about 200 feet), and even 1 in 8. These gradients are a severe test for the motor-cars, but they are overcome successfully, and cause little difficulty.

Permanent Way.—In order to provide against the severities of the winter climate of Montreal, where the thermometer occasionally falls to 30° below zero F., it is necessary to lay the track with much care. If the moisture of autumn could gather under the sleepers, or if the water caused by winter thaws could accumulate there, afterwards to be acted upon by severe frost, great derangement of the line would result. Where the rails are laid on sleepers in macadamised roads, great care has to be observed in thoroughly tamping under the sleepers, and in packing the macadam firmly up to the level of the surface of the rail. The greater part of the system, however, has been laid in paved streets, where the pavement is of either stone or wooden blocks on a 6-inch concrete foundation, or asphalt on a similar concrete base. In such pavements it was necessary to make the surface at the rail-level thoroughly impervious to water, in order to prevent the lifting action of the pavement from frost, did the water find its way between the paving (or asphalt) and the concrete base. The experience of the winter also showed that it was necessary for the rail to be absolutely rigid in paved streets, for if there were any spring in it under the heavy motor-cars—weighing when loaded about 9 tons—the asphalt would crack and leave openings for water to enter; or it would work upon the wooden blocks on

either side of the rail, and lift them out of position, leaving in this case also spaces for water to gather. In all paved streets, therefore, the plan has been adopted of laying and bedding the rail solidly on a continuous foundation of concrete.

The sections of rail adopted are shown in *Figs. 2.* They were designed by the Author for use in the Toronto street-railway system, and were likewise taken for Montreal. In the original design the rail was $6\frac{1}{2}$ inches in height, but after a year's experience $\frac{1}{16}$ inch was added to the thickness of the head, so as to give longer life, making the total height $6\frac{9}{16}$ inches, the other dimensions remaining the same, in order that the first section might be coupled to the second without inconvenience. The weight of the rail is $69\frac{1}{2}$ lbs. per yard for the $6\frac{1}{2}$-inch height, and 72 lbs. for the

Figs. 2.

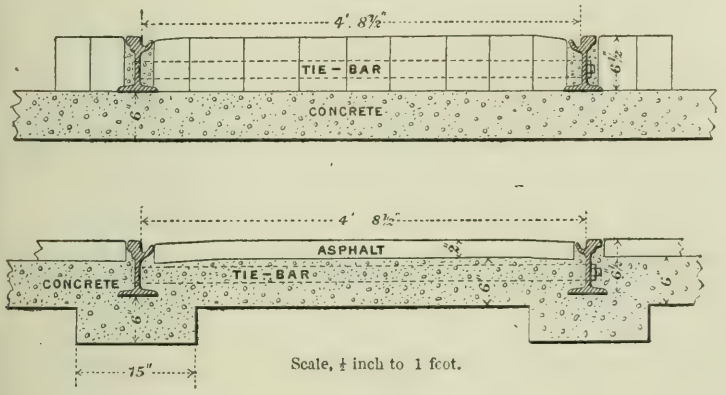


Scale, ¼ full size.

larger height. The rails were of German manufacture; about one-half the total quantity were rolled in 30-foot lengths, with 5 per cent. short lengths for curves, and the rest were in 36-foot lengths. A heavy-lipped rail, as shown in the *Figs.*, was used on the inside of curves as a guard. The manner in which the line was laid on or in concrete, in conjunction with block or asphalt paving, is shown in *Figs. 3.* The rails were set and held to gauge by tie-bars 2 inches by $\frac{3}{8}$ inch, five to each 30-foot rail-length, secured to the web of each rail by double nuts on a thread at the end of the tie-bar. When the rail was properly set to line, level and gauge, the concrete was filled in under and about it, and brought up over the base of rail to the required level of the pavement. It thus rests for its whole length on a solid mass of concrete, which is

relied on to give it stability. Before the paving blocks were reset the sides of the rail were slabbed with concrete, so as to make a square connection for the wooden (or stone) block, and this "slabbing" served the double purpose of rigidly fixing all bolts and nuts, and securely closing and protecting the copper bonding of the rail-ends from moisture. The rail thus laid is perfectly rigid, and the experience of three winters has shown the work to be in every way satisfactory. When laid in asphalt paving stone or scoria blocks were in some instances laid header and stretcher alongside the rail, instead of bringing the asphalt, up to the rail as shown in *Figs. 3.* Where there is heavy vehicular traffic this plan of laying blocks is to be preferred to the plain asphalt, as it is found that the wheels of the vehicles cut

Figs. 3.



it away alongside the rail. The concrete used in the work was made from 1 of English Portland cement, 3 of sharp river sand and 6 of broken stone. This method of construction in concrete is quite unusual in America, and, so far as the Author is aware, has been adopted only in Montreal and Toronto.

For macadamized roads in some suburban districts where traffic is light, an ordinary tee-rail of the Sandberg pattern, 4½ inches high and weighing 56 lbs. per yard, was used, being spiked to sleepers in the usual manner. The sleepers were completely buried, and the macadam filled in level with the surface of the rail. In some instances a plank 4 inches thick by 6 inches wide was laid close along each side of the rail and spiked to the sleepers, with the object of preventing the vehicular traffic from cutting a rut along the rail, and this has been found very effective.

The ends of both the tee- and the grooved rails are secured with fish-plates, the grooved rail having the long plate with six bolts 4 inches apart. This makes a very rigid and secure connection, as the plates wedge firmly between the head and base of the rail. In order to make the electrical continuity of the return as perfect as possible, bond-wires are riveted into the web at each joint with a ½-inch malleable cast-iron thimble or sleeve, slipped over the wire and driven tight, spanning across the fish-plates. These wires are of copper 0·365 inch in diameter, the same size as the overhead wire, and, as there are thus two of such wires, one on each rail, their combined conductivity is considerably greater than that of the overhead trolley-wire. In parts of the system near the power-station, where the current-density in the return is greatest, double bonding is used. The fish-plate affords considerable additional conductivity. Besides these bonds, cross bonds of similar wire are inserted at every third rail-joint to place the two rails in electrical connection, and thus assist in conveying the current back to the generators. The whole system of the rails is thus constructed in complete electrical continuity, and where the rails pass the power-station they are directly connected by copper conductors to the generators. In order, however, still further to improve the return circuit, return-wires of the same size, 0·460 inch in diameter, as the line feeders, are riveted into the web of the rails at various important points, and taken back to the generators directly by overhead insulated copper wires. In the commencement of the working earth returns were used, and the rails were connected by copper wire to cast-iron car-wheels buried about 8 feet in the soil; but considerable electrolytic action was found to be set up between the earth and gas- or water-pipes, which were injured, and in some instances charged so that shocks were received by men when opening hydrants with metallic wrenches. It was therefore determined not to use the ground for this purpose, and to construct a complete metallic return. In Boston, where there is a large service, great trouble has been experienced from electrolysis by the use of earth returns, and the best practice is now to employ complete metallic circuits.

Trolley-wire.—The trolley-wire used throughout the system is of bare copper 0·365 inch in diameter. One wire is suspended at a height of between 18 feet and 20 feet over the centre of each track. The general method of suspension is from poles between 110 feet and 120 feet apart at the kerb line on either side of the street. A span-wire of three twisted galvanized-iron wires, 0·114 inch in

diameter, is stretched across from pole to pole, and at the point directly above the centre of the track a small metal bracket is fixed, carrying on its lower side a clip to hold the trolley-wire. Between this clip and the point of contact with the span-wire there is mica insulation, so that the trolley-wire is insulated from the span-wire. At the attachment of the span-wire to the poles insulation is again effected by the introduction of a ball of mica having two galvanized-iron loops on either side (the Brooklyn strain insulation), to which the span-wire and the bolt through the pole are attached. The trolley-wire is thus doubly insulated from the poles. Where there is a double line on the street there are two trolley-wires upheld on the same span-wire, one over each line. Both wood and iron poles are used, iron in the central and wood in the suburban parts of the town. The wooden poles are of cedar, 30 feet long and 7 inches in diameter at the small end, set 6 feet into the ground. The bark is peeled off above the ground, and the pole is dressed and painted. The iron poles first used were made from malleable-iron gas-pipe of three sections, the lower section being 6 inches, the intermediate 5 inches, and the upper 4 inches in diameter. The sections are fitted together, one within the other, and secured with steel wedges, and an iron collar is placed around the point of junction. Latterly the iron poles have been made in two sections only, 6 inches and 5 inches in diameter, the lower 6-inch part being 18 feet long, and the 5-inch part 12 inches long, set 2 feet into the 6-inch piece, thus giving a total length of 28 feet for the finished pole. More recently heavier iron poles, to carry the heavy feed-wire system are employed. They are constructed in three sections respectively 8 inches, 7 inches and 6 inches in diameter, with a total length of 30 feet. The pole terminates by a top having brackets for carrying the feed-wires, fixed on a piece of solid wood 2 feet long, which fits into the top section of the pole. The iron poles are set in concrete. The hole for the pole is dug 6 feet deep and about 20 inches in diameter; the pole is then set in on a flat stone in the bottom of the hole, which is filled in with Portland-cement concrete well rammed and beaten. The concrete is made of 1 part of English cement, 3 of sharp sand, and 6 to 8 of broken stone. The pole is set with a slight rake backward, about 1 in 20, from the line of the span-wires. The total length of the pole is 30 feet, of which 24 feet are above ground, but the span-wires sag down in the span of the street, so as to bring the trolley-wire to the required height above the rail. Such sag is advantageous, as the strain of the trolley-wire on the posts is diminished, and it

accommodates itself more readily to the pressure of the trolley-pole carried on the roofs of the cars.

In some instances the trolley-wire is carried by a central line of posts placed between the double lines. In this case the lines are 6 feet or 7 feet apart in the clear, the usual distance being 4 feet or 4 feet 9 inches, and an iron bracket placed on either side of the post stretches out over each line and maintains the trolley-wire centrally above it. When the streets are sufficiently wide, the centre-pole is preferable to the side-pole method, as the poles can be used for carrying electric lamps, and may be made otherwise ornamental. The trolley-wire is well insulated from the bracket similarly as from the span-wire.

In the central parts of the town, where there are numerous telephone- and telegraph-wires, guard-wires are stretched above the trolley-wire to prevent a broken telephone- or telegraph-wire from coming into contact with the trolley-wire and causing a short circuit. These guards consist of light iron-wires, 0·114 inch in diameter. Spans are stretched from pole to pole supporting two longitudinal wires, where there is double line, at a height of about 2 feet above the trolley-wires. There have hitherto been no accidents caused by interference with telephone-wires. The overhead wire is divided by breaks into several sections, each independently fed from the power-station. The current was at first supplied to the trolley-wires connected in one continuous system; but it was soon found that if an "earth" occurred at any point, it affected the whole system and stopped all the cars. By dividing the system into various independent sections, trouble on any one is felt there only, and does not affect the others. Each section is fed directly from the power-station by feed-wires, and has its own system of return-wires.

The feed-wire and return-wire mostly used are 0·460 inch in diameter, but within a $\frac{3}{4}$-mile radius of the power-station heavier insulated feed- and return-wires are being inserted, about 1 inch in diameter, carrying a safe current of about 600 amperes. Ten such wires lead out from the power-house, and ten others of the same size act as return-wires, allowing for a total output of 6,000 amperes. The difference of potential maintained at the generators is 550 volts.

Power-Station.—A general plan of the boiler-house and engine-room, constituting the power-station for the entire system, is shown in Figs. 4, Plate 6. The building is situated, Fig. 1, Plate 1, in William Street, and is fairly central to the system, while convenient to the Lachine Canal, whence water is obtained for

condensing purposes, and to the coal wharves. The necessary proximity to the canal involved a low level, and, as Montreal has suffered from floods in the spring owing to ice jams in the river, precautions had to be taken to prevent the power-station from being injured by these floods, and to insure that, though the flood did occur, the engines might continue to work. For this reason the floors of the boiler-house and engine-room are raised about 7 feet above the level of the adjacent street.

The boiler-house is 96 feet wide at the back by 120 feet wide at the street front, with a depth of 113 feet, including the chimney stack. There are fifteen Lancashire boilers, built by Messrs. Daniel Adamson, of Dukinfield, Manchester. They have solid welded flues, jointed together by Adamson expansion-joints, and are constructed of $\frac{9}{16}$-inch steel plates with $\frac{11}{16}$-inch steel end-plates. They are 98 feet long by 7 feet in diameter, with double furnaces for each. They develop each 300 HP., and carry a working pressure of 125 lbs. per square inch. Each boiler is fitted with a dead-load safety-valve, a 6-inch steam-nozzle, a combined low-water alarm and safety-valve, and a government pop-valve on the cover of the manhole. The dead-load valve is placed towards the front of the boiler and the others follow in the order named. The boilers are arranged in two batteries. The gases from each furnace, after passing through the boiler flues, return under the boiler and along its sides to the main flue leading to the chimney. They then pass, at a temperature of between 439° F. and 480° F., into Green economizers placed on either side of the chimney, which heat the feed-water to a temperature of about 260° F. The temperature of the gases entering the chimney is between 225° F. and 250° F. By a reserve flue the gases can be sent directly into the chimney when the economizer has to be cleaned or repaired. The chimney is 180 feet high above the fire-grates, and is built with an air-space extending to within 30 feet of the top. The core is circular, of an inside diameter of 9 feet. The foundations are 42 feet square, and were excavated to a depth of about 8 feet below the street-level. Piles were driven in rows at 3-foot centres, and the whole excavation was filled with Portland-cement concrete, to a depth of 4 feet, on which the foundation masonry was laid. The draught is regulated by two Locke automatic regulators, one for each battery of boilers. The feed-water is supplied to the boilers by two pumps, built by Northey and Company, of Toronto, having steam cylinders 12 inches in diameter, the ram being 7 inches in diameter, with a stroke of 12 inches. There are also

two similar spare pumps, one on each side of the house. The feed-water is obtained from the condensing-water after condensing, and enters the economizers at an average temperature of 90° F. The main steam-pipe is 18 inches in diameter, and there is a duplicate system entering the engine-room at either end of the boiler-room. Valves are arranged so that the engines can be fed from either end of the room. The steam-piping is of solid welded tubes with riveted cast-steel flanges. Each boiler is connected to the main by a "goose-neck" pipe, to allow for expansion. All the steam-pipes are covered with asbestos coating, each boiler being covered with the same material besides being bricked over.

Bituminous coal from Cape Breton is used, of an evaporative power of $6\frac{1}{2}$ lbs. of water per lb. Until recently Run-off-mine coal was employed, but since June, 1895, screenings have been burnt with very satisfactory results. Their cost is considerably less than Run-off-mine coal, and the quantity consumed per electrical horse-power developed is but little greater. The percentage of ash in the Run-off-mine coal is 9 per cent., while for the screenings it is $11\frac{1}{2}$ per cent. A record of the operation of the power-house from October, 1894, to July, 1895, is given in the Appendix.

The water-supply for condensing and steam purposes is drawn from a basin of the Lachine Canal, a distance of 845 feet, through a 20-inch cast-iron pipe laid in the adjoining streets, and the heated water, after condensing, is returned through a similar pipe to another canal basin. For a period of about a fortnight in the spring of each year the water is run off the canal for cleaning and repair purposes, and during that time water has to be taken from the city mains, and the engines have to run non-condensing. The increased amount of fuel used during thirteen days in the month of April when the engines were driven non-condensing, being 3·93 lbs. per electrical horse-power as compared with 2·89 lbs. when condensing, is shown in the Appendix.

The ashes are ejected through a small door in the floor in front of each boiler, and are shot into the space beneath the coal platform. As the floor of this space is on the street-level the ashes are easily removed by carts driven in from the street.

The engine- and dynamo-room is 235 feet long by 89 feet wide. The roof is double, being supported in the centre by a row of steel lattice-columns, and consists of trussed steel girders, covered with 5-inch by 2-inch spruce planks on edge coated with tar-paper and gravel; the surface is flat, with a slight pitch towards the outer walls. The arrangement of the windows and skylights is such as to give abundance of light. In this room there are six horizontal

cross compound condensing-engines, developing 600 HP. each at the most economical point of cut-off, with a boiler pressure of 125 lbs. per square inch, built by the Laurie Engine Company of Montreal. The cylinders are 24 inches and 48 inches in diameter, and are steam-jacketed. They have a stroke of 48 inches, and are fitted with Corliss valves. The diameter of the driving-wheel is 22 feet; the face of the wheel is 54 inches broad, and the speed is 70 revolutions per minute. The weight of the driving-wheel is 40 tons, and that of the rim was required to be at least 70 lbs. per HP. or 42,000 lbs. The peripheral velocity at 70 revolutions is nearly 4,900 feet per minute. The total weight of each engine is 85 tons. The wheel-pits are constructed of sheet-iron, and are watertight, to prevent a possibility of trouble from water in the event of a flood. The governors are of the Porter type, and are capable of controlling the speed of the engines within 2 per cent. of the normal speed between no load and full load, and *vice versâ*. A safety governor with an automatic stop-valve is also fitted to each engine, so that the supply of steam is shut off when the speed increases 10 per cent. above the normal. The engine is thus prevented from racing should the ordinary governor get out of order. The engines are placed in a row next to the boiler-house, 26 feet from centre to centre. The foundations consist of cement-concrete and brick in cement, and are carried down to a depth of 15 feet below the level of the engine-floor. The lower part, for a depth of 7 feet, is a mass of concrete and boulders; the upper part, for a depth of 8 feet, is brick in cement. The foundation-bolts of the engines are passed through specially-built holes in the foundations to a depth of 8 feet; and a system of tunnels is constructed by which the lower end of each bolt can be reached and the nut removed without disturbing the masonry. The weight of the foundation is about six and a half times that of each engine. At the end of the engine-room there is space to erect two more engines of similar size when the traffic of the system requires it.

In the basement below the engine-floor are placed the condensers, one for each engine, five being made by Messrs. Worthington and Company, of New York, and one by Messrs. Northey and Company, of Toronto. The steam-cylinder is 12 inches in diameter, and the water-cylinder 15 inches in diameter and 10 inches stroke. The level of the condenser-floor is somewhat below the street-level, and, as the surface of the canal water is about 4 feet above the street-level, the water flows into the condensers, requiring but little assistance from the pumps.

The generators are arranged in rows opposite to the engines.

Each of the first three engines drives four Edison generators, developing 200 kilowatts each. The driving-wheel of the engine is double-crowned, and carries two pairs of belts, driving 41-inch pulleys, fixed on the armature-shaft of the generator. Each of the three remaining engines drives a pair of multipolar generators by one 52-inch belt on one pulley, 48 inches in diameter. The two generators are mounted on the same bed-plate, with the pulley between them. The armature-shaft and the pulley-shaft are in alignment, and are connected by two Hirt friction-clutches. By this means the generators can be driven together or separately. All the generators were made by the Canadian General Electric Company, at Peterborough, Ontario. They are supported on a continuous length of foundation wall, built in brick and cement, and sufficiently massive to be free from vibration.

The conductors from the generators to the switch-board pass through the basement, and are supported on racks with special porcelain insulators. Those of the 200-kilowatt generators consist of thirty-six insulated cables, each about 0·5 inch in diameter; and those for the 300-kilowatt generators consist of eighteen stranded insulated cables, each about 1·0 inch in diameter. Each generator thus has three cables—one for the positive, and one for the negative side, and the third as an equalizer. In order to equalize the resistance between several of the generators and the switch-board, the same length of cable is allowed for each generator, the additional length for those near the board being taken up by doubling back the cable in the basement.

The switch-board is constructed of terra-cotta lumber cemented on the face with adamantine plaster. The lumber consists of a mixture of clay and sawdust baked to a hard consistency. It is made by the Rathburn Company, of Deseronto, Ontario, in hollow bricks, 12 inches long by 8 inches wide and 4 inches deep. The switch-board consists of a wall of this material, 1 foot thick, 62 feet long and 18 feet high, built at one end of the engine-room, with a 6-foot space at the back and a gallery in front, raised 7 feet above the engine-room floor. The advantages of this board are that it gives very high insulation; holes can be easily drilled in it with an auger, but it is not liable to breakage, and is inexpensive. No iron frame is required in its construction. One half of the board is devoted to the instruments in connection with the generators. These consist of an ampere-meter, a triple-pole switch, an automatic magnetic circuit-breaker, and a switch for opening the shunt-circuit of the dynamo operating through a resistance. The rheostats for regulating the generators are under the gallery,

each being directly below the instruments of its particular generator, and operated from the gallery by a shaft extending through the floor. Upon the other half of the board are placed the instruments of the twenty-four feeders of the system, which is divided into nine independent sections. For each feeder these instruments consist of an ampere-meter, automatic magnetic circuit-breaker and a switch. At the end of the switch-board, and at right angles to it, are placed the volt-meter and the general ampere-meter, together with a barometer, thermometer, and a recording volt-meter. At the back of the switch-board there is a tank lightning-arrester, which is thrown into circuit when there are indications of electrical atmospheric disturbance. The highest reading yet obtained on the general ampere-meter was 5,750 amperes, in the month of July, at the time when there were one hundred and fifty-one motor-cars and seventy-five trail-cars running on the system, carrying a very heavy load of passengers.

Rolling Stock.—The rolling-stock equipment in the summer is one hundred and sixty-three motor-cars, of which fifty-one are open. In winter it is one hundred and forty-five closed cars with double motors, and fourteen snow-sweepers with triple motors. There are besides, fifty-three open trail-cars, and sixty closed trail-cars, being those of the former horse-system. The standard closed car has a body 18 feet or 21 feet long (having a maximum length over all of 28 feet 6 inches), with platforms at either end projecting 3 feet to 4 feet, and entrance-doors at each end. The width is 7 feet 6 inches, and the seating capacity is twenty-six. The seats are arranged longitudinally on either side of the car, with a central passage. This car-body is mounted on a single-steel truck with heavy forged frame. The truck frame is 15 feet long, and at its extremities there are two rolled-steel elliptic springs, which, from their extended position, steady the car-body and prevent rocking. The truck has two pairs of 33-inch cast-iron wheels, with chilled tread, weighing 360 lbs. each, the axles of which, $3\frac{3}{4}$ inches diameter, are placed 7 feet from centre to centre. The standard open car is of the same length as the closed car. There are nine, and in some cases ten, cross-benches arranged in the car, with reversible backs, so that the passengers face the direction in which they are travelling. These cars can seat forty or fifty passengers. The same truck is used under these as under the closed cars, and in summer trucks with their equipment are transferred from the closed to the open cars. Some small open cars, formerly horse-cars, having seven cross-benches, are used on level routes, with only one motor mounted on the truck. The trailing-

cars are coupled one to each motor-car, and are used on certain routes and at certain hours of the day when the traffic is heavy.

The motors are of various types, such as the Edison, the Westinghouse, the Thomson-Houston, the Royal Electric (Montreal), and the General Electric. The Westinghouse and the General Electric motors, rated at 25 HP. or 30 HP. each, are the most recent types, and are efficient and economical. They are all of the single-reduction type. A pinion fitted on the armature-axle works into a gear keyed on to the axle of the truck-wheels. The ratio of the pinion- to the gear-wheel differs slightly in different types, but it is generally about 4 to 1 (22 inches and $5\frac{1}{2}$ inches). Two motors are fitted to each truck, with the exception of the small open cars, each motor being geared to each of the axles. A car with a heavy load of passengers can easily be driven up the 10 per cent. gradients of the system thus equipped, and on the less hilly routes a motor-car can readily draw a heavily-loaded trail-car, besides taking a full load itself. The average speed of the cars is about $7\frac{1}{2}$ miles per hour.

The controllers used on the cars are of the Westinghouse series-parallel type, and those made by the Canadian General Electric Company, the latter being the more recent. As their name implies, these controllers place the two motors in series, when the current is first applied. When a certain speed has been attained, and more current is admitted, the controller places the motors in parallel. The number of watt-hours consumed per ton-mile have, as shown in the Appendix, steadily decreased since October, 1894, doubtless largely due to the use of an efficient controller.

The trolley-pole by which the current is conducted from the overhead wire to the motors is formed of steel pipe. It is 12 feet long, tapering from 1 inch outside diameter at the top end to $1\frac{1}{2}$ inch diameter at the lower end. It is mounted centrally on the roof of the car on a base that swings on a pivot, and can thus be reversed at will. The base is fitted with springs holding the wheel, carried at the extremity of the pole, against the wire with a pressure of about 15 lbs. If the pressure is too light, sparking takes places between the wheel and the wire. The trolley-wheel is 4 inches in diameter, formed of hard brass, and is carried on the end of the pole by a "harp" fitting into the inside of the pole. It has a groove on the rim $\frac{3}{4}$ inch deep, so as to give a hold on the trolley-wire, and is made with open spokes, four in number, in order to reduce its weight. It is fitted with graphite bushing, so that no oiling is required. The pole, when in service, is inclined

to the roof of the car at an angle of about 45°. These steel poles have been found much more serviceable and less likely to get out of order than the wooden poles first employed.

Each car is fitted with a fender consisting of a flat tray, hooked on to the front of the car, projecting 2 feet 9 inches, and carried 6 inches above the rail. The frame is made of $\frac{3}{4}$-inch round iron, and the floor is formed of strips of thin flat iron $1\frac{1}{2}$ inch wide interlaced. The arrangement is very simple, but it has been effective in saving a number of persons, particularly children, from injury or death.

The cars are lighted at night by incandescent lamps, using the current from the overhead wire. The trail-cars are also connected to the motor and lighted in the same manner. In winter the cars are heated by small stoves, burning anthracite coal. Experiments have been made with electric heating, and during the winter of 1894–95 one car was heated by this means. The quantity of current required, however, to bring the car to a moderate temperature in such a winter climate as that of Montreal, where the thermometer sometimes falls to 25° or 30° below zero F., makes this method too expensive for general adoption. The average power required is 5 HP., and on cold days 9 HP. per car. The cost of the coal stoves, including fuel and labour, cleaning and lighting, is about $7\frac{1}{2}d.$ per day of twenty hours; whereas by electricity the cost is about $3s.$ In a less rigorous climate than Montreal, or where the power was generated by water instead of fuel, the electric heater might well be used. There is no dust or dirt from it as from the stove, and, being placed under the seats, it occupies no seating space as does the stove.

Considerable trouble is experienced in keeping the lines clear for the running of the cars during the winter season; but during the past three winters the work has been successfully accomplished. The average annual snowfall for the past nineteen years has been 119 inches. The agreement with the City Council is that the Company keeps the lines free of ice and snow, and that the city then removes the snow cleared off, together with such other quantity as may be necessary to keep the streets in good condition for sleighing; and the Company pays one-half the cost of this removal. In order to clear the lines of snow, electric sweepers are used. Nine of these were in service during the winter of 1894–95, and fourteen during the winter of 1895–96. The body of the sweeper is 18 feet long, and it is carried on two pairs of 33-inch wheels and axles attached directly to the body. To each axle is geared a 30-HP. motor for driving the car. A

third motor is placed in the car to drive the rotary brooms, of which there are two, each placed diagonally across the car at an angle of about 45°, one in front and the other in rear, and actuated so as to throw the snow out from the line on to the roadway by the sides. The broom is formed of rattan cane. The snow is then removed by sleighs on to vacant grounds, or to the river when the ice sets. In summer, the motors are removed from the sweepers and used on cars.

Repair-Shops.—The repair-shops of the Company, of which a general plan is shown in Figs. 5, Plate 6, are situated in the central part of the town. Formerly the stables of the company occupied this site, but these have been converted into workshops and car-sheds. On the ground floor are iron-working machines, and on the second floor wood-working machines necessary for the repair and construction of cars. All the electrical repairs are also carried on here, and armatures of every type re-wound. The machinery is driven and the lighting effected by current from the power-house. By an electrical lift cars are taken from the lower to the upper storey. The pits in the lines on the ground floor are deep, so that men can get freely under the cars to examine and repair them. The buildings are heated by steam in winter. At three other points in the city there are also sheds for the storage of cars, and for their examination and over-haulage at night, between the hours of midnight and 5 A.M.

Working.—The increase in the traffic on the system since the introduction of electricity in September, 1892, has been very marked, as is shown in the following Table:—

STATEMENT OF OPERATIONS OF MONTREAL STREET-RAILWAY.

—	Year ended 30th Sept. 1892.	Year ended 30th Sept. 1893.	Year ended 30th Sept. 1894.	Year ended 30th Sept. 1895.
Gross passenger receipts	$564,406·57	$750,751·78	$896,090·89	$1,102,777·57
Operating expenses .	$466,644·98	$593,041·71	$637,668·14	$652,811·74
Operating expenses, per cent. of earnings	82·68	79·0	71·16	59·20
Passengers . . .	11,631,386	17,177,952	20,569,013	25,877,758

As the present year is the first during which the system has been worked entirely by electricity, the horses not being entirely superseded until September, 1894, it is impossible to make comparison with any preceding year. The cost for July was almost exactly $3\frac{3}{4}d.$ per car-mile, and during that month the cost of power was less than $\frac{1}{2}d.$ per car-mile. For the year the cost was

$5\frac{1}{3}d.$ per car-mile; and the average cost of power was slightly under $\frac{3}{4}d.$ per car-mile. This, besides the ordinary items of cost, includes all the expense of snow-removal, insurance, taxes, legal expenses, injuries, damages, &c.

In the Appendix the aim of the Author has been to follow the line of thought developed in his Paper on "The Energy of Fuel in Locomotives."[1] The main object is to show the energy expended, in pounds of coal, per unit of work, in ton-miles. In that Paper it was shown that on the Canada Southern Railway a ton was moved in freight service 1 mile with as small an expenditure of fuel as 2·3 ounces. At the same time in passenger service the consumption of fuel varied between 1·13 lb. and 0·80 lb. per ton-mile. In the passenger service worked by electricity on the Montreal street-railway, as shown in Table I, the consumption varies between 1·18 lb. and 0·94 lb. per ton-mile, disregarding the abnormal period of thirteen days when the engines were running non-condensing. A very remarkable agreement is shown which goes to prove that in electrical work the loss entailed by the transformations from mechanical to electrical, and then again to mechanical energy, as also from its conveyance over distances of 3 miles and 4 miles, is compensated for by the more efficient engines and boilers of the power-house being able to develop a larger percentage of the energy of the fuel than the locomotive can realise. Few machines are so wasteful of energy as the locomotive, while in a power-house the most economical types can be used, in conjunction with the most effective and delicate appliances for conserving heat.

In the passenger service of the steam road a much higher speed was maintained than on a street-railway, and this high speed necessitated a large consumption of energy; on the other hand, however, the frequent stops and startings, together with the heavy gradients of the street-railway consume energy to perhaps a greater extent than high speed. On an average mile of street an electric car would stop and start oftener than an express train would on 100 miles of railway. It seems probable from these figures that an electric train running at 30 miles an hour on an ordinary railway line would consume less fuel per ton-mile than a locomotive, and the quality of the fuel used in the power-house would be much inferior to that burnt by a locomotive. It must also be borne in mind that the results shown in the Appendix have been obtained from compound engines only. There is no

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 321.

reason why triple and quadruple expansion engines should not be used in a power-house, and a still further economy of fuel thereby effected.

In the column "Watts per ton" there is a very noticeable decrease in the amount of power used, from 2,716 watts in November to 2,048 watts in May. Part of this decrease is due to the improved condition of the line in May as compared with November; but the whole of it cannot be attributed to this, for it will be seen that the power steadily decreased during the worse winter months. During this time the cars were being fitted with more efficient controllers, and the effect of these in economising power was steadily growing. With the improvements that will certainly be effected in electrical machines, further savings of power will be effected, and a consequent decrease of the amount of fuel consumed per ton-mile from this cause.

Fluctuations in the amount of coal consumed per horse-power hour are due often to one or other of the economizers being out of use for repairs. With only one economizer in service the temperature of the feed-water would fall from 260° to 190°, and this would cause an additional consumption of fuel.

The greater part of the constructive work up to March, 1894, was carried out under contract by Mr. James Ross of Montreal, and Mr. William Mackenzie of Toronto. Since that date the work has been carried on for the company by the Author. Up to May, 1894, Mr. W. H. Brenner occupied the position of electrical engineer, and from that date to June, 1895, that post was held by Mr. R. C. Brown. The Author became chief engineer to the company in August, 1892, at the commencement of the work of reconstruction; and since the autumn of 1893 has occupied the combined position of manager and chief engineer.

The Paper is accompanied by a map, four photo prints and six photographs, from which Plate 6 and the *Figs.* in the text have been prepared.

APPENDIX.

COAL CONSUMED, AND POWER DELIVERED, FROM WILLIAM STREET POWER-HOUSE.

Period.	Coal Consumed.	Car-Miles Run.	Coal Consumed per Car-Mile.	Passengers Carried Per Car-Mile.	Ton-Miles.	Coal Consumed.		Total Output.	Watt-Hours.			Coal per E.HP. Hour.	Watts per Ton of Motor-Cars.
						Per Ton-Mile.	Per Passenger-Mile.		Per Motor Car-Mile.	Per Lb. Coal.	Per Ton-Mile.		
1894.	Tons.		Lbs.			Lbs.	Lbs.	E.HP. Hours.				Lbs.	
October . . .	1,512·8	492,606	6·8	4·2	3,136,609	1·07	1·6	1,233,998	2,103	271	293	2·74	2,608
November . .	1,426·6	436,918	7·3	4·3	2,831,988	1·13	1·7	1,203,318	2,228	281	317	2·65	2,716
December . .	1,434·8	409,826	7·8	4·4	2,706,802	1·18	1·8	1,179,847	2,275	274	325	2·72	2,690
1895.													
January . . .	1,419·4	402,324	7·8	4·4	2,674,140	1·18	1·8	1,134,686	2,190	266	316	2·80	2,567
February . .	1,350·7	384,983	7·8	4·2	2,549,713	1·18	1·9	1,044,387	2,111	256	305	2·90	2,473
March . . .	1,502·0	457,084	7·3	4·1	3,006,704	1·11	1·8	1,203,387	2,071	266	298	2·79	2,343
April 1 to 17 .	857·8	266,168	7·2	4·05	1,760,554	1·09	1·78	663,654	1,942	257	281	2·89	2,195
April 18 to 30 .	940·3	227,278	9·3	4·05	1,463,610	1·44	2·28	535,958	1,926	190	273	3·93	2,145
May	1,674·6	629,075	5·8	3·7	3,892,379	0·94	1·55	1,354,978	1,877	274	259	2·72	2,048
June	1,688·6	656,573	5·7	4·0	3,981,585	0·95	1·44	1,369,049	1,893	270	256	2·76	2,057
July	1,858·8	693,459	6·0	3·7	4,216,750	0·98	1·57	1,474,124	1,910	264	260	2·82	2,100

Discussion.

Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., moved that the thanks of the Institution be accorded to the Author for the valuable Paper he had communicated on an interesting and important branch of electric traction.

Major-General Webber.

Major-General WEBBER thought engineers would be impressed by the conditions on the continent of Europe, as compared with those existing in England, as to the facilities for the construction of electric tramways. The method of laying tramway rails on a macadamised road, in which a plank was placed alongside the rail with its upper surface level with the top of the rail, had been referred to in the Paper, as a means of preventing the wheels of the ordinary traffic cutting a rut along the rail. It would be interesting if the Author would explain how it was that a rut was not caused equally alongside the plank. The advantage existing in Montreal, and no doubt in many towns, not only in the United States, but in Canada, arising from the permission to carry feeder-wires overhead was also brought out in the Paper. Although overhead conductors were allowed in many of the most important continental towns, he did not remember a case in which the ordinary trolley-wire had been supplemented by overhead feeder-wires attached to brackets from the poles. All, or most of, the feeder-wires on a well-constructed line, were laid underground, and they were therefore more costly than when carried overhead. That applied to a most excellent arrangement also existing in Europe—the use of heavy return conductors. If he understood the Paper rightly, these were also carried overhead. That was a factor of economy which he did not think would be allowed in Europe. The spans between the poles—about 120 feet—were, he thought, rarely allowed in any town in Europe, where, in most cases, they did not exceed 90 feet. He had lately inspected some of the most important tramway-systems in Germany, and he could not help thinking that, although there might be a considerable difference in the actual conditions of old towns like Hamburg, the suburbs presented very similar aspects to what might be found in most of the newer cities in America. He did not regard Montreal as a new city, but so far as the suburbs were concerned he could well understand that an overhead system was allowed, and was not a disfigurement. But the more he saw of the overhead systems

in the suburbs of the towns he had visited, the more he felt that the only reason why those lines of gallows were permitted was that most of the roads were so dreary in character that the overhead trolley line was an ornament rather than a disfigurement. The only case in which he recollected an overhead trolley-line having been allowed with little or no objection in a picturesque place was the first line of the kind erected in Europe, with the design of which he had been concerned, at Montreux, alongside the Lake of Geneva. When he last visited it the trees had so concealed the poles that they were not noticed. In Hamburg, where there was a system almost identical in size and power with that described in the Paper, one great objection was removed in the narrow streets, that there were no poles, the trolley-lines being suspended by wires stretched from house to house. The effect on the expenditure of energy of a considerable length of the line referred to in the Paper, having heavy gradients, had been illustrated by some of the figures if his deduction from them was correct. The 151 cars in fine weather increased the current to 5,750 amperes. In bad weather this would run up to 25 per cent. higher, or to 7,190 amperes. The average might be taken as 65 per cent., or 17 units per hour per car, or 2·25 units per car-mile in bad weather. In Hamburg, where the length of steep gradient was much less of the total of 94 kilometres, the 310 cars always on the line did not use much more than half that amount, measured at the terminals of the generators. If the Author would show how many car-miles were run with the motor-cars, and how many with motor-cars and trailers, it would be easier to judge better of the results. The average speed of 7½ miles was the resulting factor of a large portion of the length of the line having heavy gradients. In Hamburg, with a lower consumption of electrical energy per car-mile, the cars attained on some roads a speed of 19 kilometres per hour without appearing to cause danger to the pedestrian or wheel-traffic. There was one point which was of great interest in this country—the question of stopping-places. He should be glad to know whether the municipality of Montreal allowed a regulation by which the cars might stop at certain points at the corners of the streets, not making it obligatory to stop wherever any old apple-woman hailed the car. Any one who observed what happened in Streatham, where there was an analogous case, must be struck with the way in which the tramway traffic was interrupted by unnecessary stoppages. Passengers using the line seemed to take pleasure in requiring the car to be pulled up every moment. The

Major-General Webber.

Major-General Webber.

inconvenience would occur just as much with electric-traction as with cable-traction.

Mr. Dawson.

Mr. P. Dawson remarked that the capital investments in electric street-railways in the United States, which amounted to £50,000,000, and the aggregate station I.HP. used to propel electric cars in America was about 1,500,000. With reference to the Author's statement that there were 15 miles or 20 miles of accumulator storage-battery roads running in the United States, he should be glad to know in what other places they were running. The only one of which he knew was in New York, and on that road at the end of 1895 there were only two experimental cars running. Cars carrying accumulators, self-contained motor-cars, had been used 10 years or 15 years, and had always proved a financial failure. For practical purposes the conduit system was perfectly satisfactory, and had been running for some years on the Continent. At Buda-Pesth it had been running on a line 4 miles in length. It was also used in Lennox Avenue, New York, and had been likewise working successfully at Washington. The only objection to it was great prime cost. The cost of equipping the installation in Lennox Avenue was about £17,000 for a single mile of line. The cost of the trolley system was only one-third of that amount. On the tramways in the United Kingdom where the dividends were not very large, such an increase of capital expenditure could not be recommended from the investor's standpoint. There was also a conduit in course of construction in Brussels. There had been already an overhead wire there for some years, which had been most successful. It was built mostly with bracket arm-poles, 120 feet apart, with ornamental brackets running out along the Boulevard, and it was quite practicable, and no eyesore. There was another line, in the heart of the city of Bristol, with which he had been connected. It had been running since October, 1895, without a hitch. The placing of tramway rails on ordinary macadam roads had been referred to by Major-Gen. Webber. A small line had been running for several years at Guernsey, three miles in length, one mile being laid with tramway rails on a macadamised road. There was a fairly heavy traffic, and the road was well maintained, there being no rut whatever. As to the question of bonding, he did not think the corrosion of water- and gas-pipes, and possibly of telephone- and telegraph-cables, which might be caused by the escaping of the electric-current over the rails on its way back to the generating station was to be feared in England on account of the stringent Board of Trade rule, which could easily be complied with, as had

Mr. Dawson.

been proved at Bristol. Two conditions were necessary: the first was that the rails were connected together and to the return circuit, so that the current would have an easier path to get back by the rails than by the earth, or the water- or gas-pipes in the neighbourhood. The second was to insulate as far as possible the rails from the earth. The bonding adopted at Bristol, Dublin, Cape Town, Port Elizabeth, and most of the continental lines now being equipped, was that known as the "Chicago" bond. He had placed a section of a rail on the table. It was practically a one-piece rail bond, having large tubular terminals, which were connected into the rails by inserting them into the holes drilled to fit them, and permanently expanded by stretching or swaging the metal composing them into contact with the holes. The expansion of the terminals was accomplished by driving drift-pins into them about $\frac{1}{16}$-inch larger than the openings in the tubular terminals. As the conductivity of iron was one-sixth that of copper, the contact of the copper with the iron must be six times the sectional area of the copper. That was met by making the terminal of the bond very much larger than the ordinary section. The Board of Trade enforced that there must not be a fall of potential on the return circuit, between the furthest end of the line and the station, of more than 7 volts. In Bristol, where the end of the line was 2 miles from the station, there was a regular service of twelve motor-cars, and by the use of good bonding the fall of potential was only $1\frac{1}{2}$ volt. Another point of importance in English tramways, where a concrete foundation was generally used for the rails, was that the rails were practically insulated from the earth. When there was a short-circuit on the overhead line the leak did not exceed 60 amperes. This was owing to the fact of the poles supporting the wires being bedded in concrete, which acted as an insulator, and prevented the great rush of current which would otherwise take place. With regard to the question of iron or steel poles, it was important that they should be strong enough to support the very heavy strain which they were called upon to bear. He might be permitted to read the specification of the poles used in Bristol, Dublin, and on all the recent American lines:—"Five grades of poles are called for, all of them 31 feet long, to be set in the ground to a depth of 6 feet. No. 1 is to stand a lateral strain of 350 lbs. applied to the top without showing a temporary deflection greater than 6 inches, and a strain of 700 lbs. without showing a permanent deflection greater than $\frac{1}{2}$ inch. No. 2 is to stand a strain of 500 lbs. without deflecting more than 6 inches, and a strain of 1,000 lbs. without more than $\frac{1}{2}$ an inch permanent

Mr. Dawson. deflection. No. 3 is to stand a strain of 700 lbs. without deflecting more than 6 inches, and strain of 1,200 lbs. without permanent deflection of more than $\frac{1}{2}$ an inch. No. 4 is to stand a strain of 1,000 lbs. without temporary deflection of more than 6 inches, and 1,700 lbs. without permanent deflection of more than $\frac{1}{2}$ an inch. No. 5 to stand a strain of 2,000 lbs. without permanent deflection of more than 6 inches, and 2,600 lbs. without permanent deflection of more than 6 inches. The poles are to be as nearly round as possible. A difference of $\frac{1}{8}$ inch between maximum and minimum diameter is all that will be allowed. They must all be as nearly uniform as possible, $\frac{1}{16}$ inch more or less than specified dimensions is all that will be allowed. One quarter of an inch is the greatest distance out of the true that will be allowed at the top of the pole. Ten per cent. of each lot of poles will be tested. Should three poles fail to come up to the specification, the engineer shall have the right to reject the entire lot. These poles will be dropped, butt foremost from a distance of 6 feet on to some solid substance three times, and must show no signs of telescoping or loosening in the joints." It would be seen that that was a very severe test. All the poles used in England and abroad had passed that test. It was difficult to obtain the poles in England, owing to the small demand existing for them. With regard to the question of guard wires, they had been employed in the United States, and had proved more a nuisance than a benefit, and in many installations they were left out. It had been found that telephone- or telegraph-wires fell and whipped round the guard wires, came on the trolley-wires, and caused short-circuiting. An alternative which had been applied was a small rectangular strip of wood fixed to the top of the trolley-wire by means of clips. Wherever those wires crossed the trolley-wires another system had been adopted at Dublin, an arrangement had been entered into with the telephone authorities to replace their telephone-wires on that portion by an insulated telephone-wire, so that if it dropped it would do no damage. He observed that most of the generators in the station were driven by belts. Nearly all the generators used in Europe and in America, were direct-driven when their duty exceeded 300 HP. Very large generators were at work in Brooklyn, St. Louis, Philadelphia, Boston, and several other cities. In Brooklyn there was a system working 1,500 cars from three stations. The units were 2,000 HP., and each generator was directly coupled to a triple-expansion condensing Corliss engine, running at 75 revolutions per minute. The fly-wheel was 24 feet in diameter, and

weighed 65 tons. The main bearings were 18 inches by 48 inches. The armature was 120 inches in diameter, and 36 inches wide. The generator had twelve poles, and the weight of the armature was 27 tons. The complete engine and dynamo weighed 360 tons. The ratio of E.HP. at the switch-board to I.HP. at the engine was 87 per cent.; and the average coal consumption per Board of Trade unit was 2·4 lbs. The machine gave a pressure of 550 volts at no load, and 600 volts at full load. It would stand sudden variations of load equal to the total of its capacity without sparking, and it would bear 50 per cent. of overloading for several hours without danger. The machine had been working at the Brooklyn Power Station two or three years, and had been designed by Mr. H. F. Parshall. The Paper had described several trucks used at Montreal, and he had thought it might be interesting to bring for inspection the model of a truck such as was now used at Bristol, Coventry, and Dublin, and to a very large extent in America. There were two G. E. 800 motors capable of exerting a pull of 800 lbs. on the periphery of the wheels at the normal speed for which they were designed. It would be seen that the truck was very different from the type of truck generally used in England. The weight of the motor-car was much greater than that of the horse-car. The two motors weighed about 30,000 lbs. and each motor was rated at 25 HP.; the motor, car-body, and passenger load would not weigh far short of 10 tons. At Bristol the directors of the company had realized, when electrical power was introduced, that the frequent stoppage of the cars would cause a great waste of energy. The amount required to start a car was far more than that necessary to run the car, and therefore the average cost would be greatly increased. There were consequently fixed stopping-places, indicated by marks on the poles, a plan which had succeeded from the first and involved no trouble. The trucks had two sets of elliptical springs when the truck was lightly loaded, and heavy coil springs acting when the car-body was nearly loaded with passengers. The truck was suspended from the axles by a double set of springs. There were two coil springs, one outside the other, and one heavier than the other. They bore the jars of the road according as they were lighter or greater. Both passengers and motors had a double spring suspension between them and the rail. There was a different condition from that prevailing in America. In America there were very few top-seat cars. In England they could not be dispensed with. It had been said that that was against electrical traction being introduced in this country, but that was not the

Mr. Dawson.

Mr. Dawson. case. In Guernsey top-seat cars were used; also at Bristol, Dublin and Coventry. Top-seat trolleys ran quite easily, and were used in Bristol without the slightest difficulty; he had brought for inspection by the members a trolley he had recently designed. There was another advantage in the system adopted, namely, that it gave a very large amount of play to the trolley-arm. The trolley-wire could have a deviation of 12 feet on either side of the centre line from pole to pole. A smaller number of insulators was therefore required than would be needed in America. The system was often described as darkening the street, but that did not apply to that system at all. He should be glad to know the number of trolley-cars used, and the average amount of power required to drive them, the car-mile being generally one-half to one-third of that required for the motor-car.

Mr. Parker. Mr. THOMAS PARKER believed that the overhead system was the only one applicable to the particular climate of Montreal. With regard to batteries, he might mention that at Birmingham, four years ago, he had designed and erected an installation of accumulator cars which had been running to the present day. He did not think they had been worked as well as they might have been; he was convinced that there were possibilities in connection with the accumulator-cars which had not yet been obtained, and there were cases in which accumulator-cars might be run with advantage. There was a statement in the Paper respecting the cost of power, $\frac{1}{2}d.$ to $\frac{3}{4}d.$ per car-mile per hour. There was also another statement with respect to $5\frac{1}{3}d.$ per car-mile, which included a number of conditions of service which could scarcely be compared with other results. Therefore the $\frac{1}{2}d.$ to $\frac{3}{4}d.$ for power seemed to be the feature which might be discussed. He should be glad if the Author would give a statement of figures or curves showing what were the conditions on his line—the speed he ran on the various gradients, stating the gradients and the current he used and their voltage with a load. It would be interesting, also, if he would state the full features of the motor termed 25 HP., giving the torque of the motor with given current at varying speeds with the necessarily varying voltage, weight of motor, length of active conductor and density on the armature, and the temperature to which it raised itself after six hours' running. The weight of the generators, the length of their active conductors on the armature, their peripheral velocity, the density of currents in the copper on the armature, their output in amperes with voltage, and the temperature after say six hours' running, would also be interesting. With regard to the conduit system, it would be remembered that it had been

adopted at Blackpool in the early days. He had designed and constructed that plant in 1883–4, and was associated with it as consulting engineer to the company for seven years. The economy of running on that line would compare with anything since achieved. There were special difficulties at Blackpool—the sea would run over the line and bring the sand with it; but notwithstanding these difficulties good results were obtained. Since then 4 miles or 5 miles had been laid in Madras on a conduit system. Financial difficulties had occurred in connection with it; but he thought it would be interesting to the members to have the particulars before them. In Blackpool it would be remembered that the slot was in the middle of the road, introducing a great number of mechanical and obstructional difficulties. In Madras that had been dispensed with. The underground conductors were so laid that little difficulty was experienced from the point which had generally proved a stumbling-block to their adoption. He had recently heard from one of the directors of the company that the 4 miles or 5 miles of tramway laid before the financial difficulties had worked well. The slot was in the side of the road as in the case at Buda-Pesth, but it did not exceed $\frac{3}{4}$ inch in width anywhere. The difficulty of the working of the points had been very successfully overcome. These were questions which should be thoroughly considered in view of the application of tramways to English cities. He had designed and constructed an overhead tramway in South Staffordshire, and he thought it was perhaps as successful as anything of the kind in England. The economies obtained were, he believed, equal to the best obtained in America. The cost of the Madras system was about £2,500 per mile as originally laid down. The corrosion of gas-pipes and water-pipes was an electrical problem which was not insurmountable and was a question of cost, and all such difficulties would be overcome. Mr. Parker.

Mr. W. H. Preece said that the phenomenal growth of the electrical tramway system in the United States had been referred to, not only in the Paper, but in the course of the discussion; and as one who had visited the United States in 1884, and found there only one railway, at Cleveland, it was to him a matter of great surprise to find that in the short space of twelve years one railway of about 2 miles in length had grown to 10,363 miles of railway worked by electricity. But it should not be forgotten that tramways, whether worked by electricity or horse-power, were a necessity in the United States; they were not such a necessity in this country but rather a luxury. In the United States there were not Mr. Preece.

Mr. Preece. the conveniences of locomotion existing in England. There were great variations of climate, and many reasons why the introduction of electricity as a motive power for working the lines had proved so great a financial success. Unquestionably the working of those tram lines had been far more economical by means of electricity than by means of horses. The Paper was extremely valuable, since, as mentioned by Mr. Parker, the Author had given the cost of working. He was not quite sure that the expenditure could be followed exactly, or even checked; but the Author had brought out the fact that while the total cost of working the lines in Montreal amounted to $5\frac{1}{3}d.$ per car-mile, the cost of the power expended was only $\frac{3}{4}d.$ per car-mile. In England, and he thought in the United States, it was considered that there was an expenditure of one Board of Trade unit for every car-mile run; and that was verified by what he had recently heard in Rome, where the cost amounted to 620 watts per car-kilometre, which compared almost exactly with 1,000 watts per car-mile. From the Paper, however, it appeared that the mean expenditure of watt-hours per car-mile in Montreal amounted to 1,560. It was surprising to find that there should be such a difference as that between 1,000 and 1,560 in working the tramways in Montreal as compared with the United States and with England. But he thought it was fully explained in the Paper, where it was shown that the tramways had very heavy gradients. Montreal was very hilly, and with gradients of 1 to 10, or 1 to 8, it was not surprising that there was an expenditure of energy far beyond that experienced in this country, in Europe, and in America generally. The point he wished to urge was that, if in Montreal it was possible to move the trams with an expenditure of $\frac{3}{4}d.$ per car-mile, and with an expenditure of $1\frac{1}{2}$ Board of Trade unit, it meant that it had been possible to produce and supply a Board of Trade unit to the working of the cars which was equivalent to $\frac{1}{2}d.$ per Board of Trade unit. He had in that room on several occasions pointed out as a fact that could not be too strongly urged and accepted, that if electrical energy was generated and applied for any purpose so as to use continuously the machinery at its full efficiency, and for the whole twenty-four hours of the day, electrical energy could be produced at an expenditure less than $\frac{1}{2}d.$ per unit. That was done in all cases of electro-chemical industry, and it could be done on tramways if the machinery was worked for the twenty-four hours. That it could be done was proved by the facts that the Author had brought before them. He had shown that with a load-curve for less than twenty-four hours per day the electrical energy could

be applied for an expenditure equivalent to $\frac{1}{2}d.$ per unit. That was the fact of the greatest importance to all local authorities and local industries that were now establishing in their midst installations for the purpose of generating light. An installation for the purpose of generating light was practically only used at its maximum figure for two hours during the day. But tramways were worked from early daylight till late in the evening; the maximum load of the tramway system was in the morning and in the afternoon. Now if machinery could be applied primarily to the production of electric-light at night, and secondarily to the production of electrical energy for power during the day, it could not only be produced at the figure given by the Author, about $\frac{1}{2}d.$ per unit, but in such a way as to bring down the price of electric-light at night so low as to make the cost of light comparatively insignificant, and it could be applied during the day at a price equally low so as to compare most favourably with that of horseflesh. The result was that by the application of electrical energy in towns for both working tramways and producing light the greatest possible benefit could be given to the ratepayers who supplied the funds. He had recently visited Rome, where there was in use quite a novel system. The energy that lighted 60,000 glow-lamps and 1,000 arc-lamps, and performed much other work besides, was produced primarily by water-power at Tivoli, 18 miles away, and was brought by high-pressure currents, at a pressure of 5,000 volts to 6,000 volts, to Rome. But, in addition to that, within the last twelve months Professor Mengarini had during the day applied the energy from Tivoli to charging batteries and working the tramways. The tramway hours and the electric-light hours overlapped each other for about two hours during the day. In the early hours the currents worked the trams direct, but during the overlapping hours they were worked by the batteries and the currents gave the electric-light. The result was that energy could be supplied to work tramways during the day and to maintain the lighting of the glow-lamps and the arc-lamps at night by precisely the same power. That was a thing likely to come into use in this country, for it meant economy. It was quite a novelty to find that without any apparent loss of energy, and practically with the greatest ease, alternating currents were used to charge batteries. A visitor to Rome could not spend the time better than by going to see how a purely scientific man, with the deepest insight, had developed practical instincts and sound engineering, and had utilized the immense water-power, hitherto running to waste, to light Rome and to work the tramways in that charming city.

Mr. Preece.

Major-General Webber. Major-General WEBBER assumed that Mr. Preece, in speaking of consumption, took it at the terminals of the generators per car as 1 kilowatt. At the speed given of 7½ miles per hour, the Author's figure in July gave 13 kilowatts per hour. Perhaps Mr. Preece would state, with regard to the Tivoli lighting, whether the batteries took the whole of the overlapping load? It was a common thing on the Continent for stations to generate both for lighting and traction. He should be glad to know if the cars were supplied entirely by the reserve in the batteries during the overlapping hours.

Mr. Preece. Mr. W. H. PREECE said he did not think there was anything in the Paper which could possibly indicate that 13 kilowatts per hour were consumed in moving a car. Experience in the working of tramways showed that 1 car-mile absorbed 1 Board of Trade unit when run at the normal velocity of between 7 miles and 8 miles per hour, and the Paper showed distinctly that at the same speed, 7½ miles per hour, 1·56 unit had been so absorbed. With regard to what had been done in Rome, it was quite true that during the time of full load, from four to about six o'clock, the trams were worked by batteries. There were three hundred and four very large cells of the Tudor type, having 1,200 ampere-hours' capacity, and those from day to day, without any trouble, maintained constant the voltage of the trolley-wire (550 volts) which supplied the current required by the tramway.

Mr. Parker. Mr. THOMAS PARKER wished the Author would give curves or figures showing the actual power in amperes and volts used upon the various gradients, together with the speed. The total amount of energy used per car-mile or per ton-mile did not fully state the conditions under which the tramway worked as to gradients, speeds, &c.

Dr. Kennedy. Dr. A. B. W. KENNEDY had calculated the figures as Mr. Preece had read them—1½ unit per car-mile, so that if the cost of producing a car-mile was ¾*d.*, the cost of producing a unit was ½*d.* He had not drawn exactly the same inference as Mr. Preece, but hoped that the Author would justify Mr. Preece's inference. There was in England a most salutary institution called the Board of Trade, which compelled accounts of many electrical undertakings to be issued in a form which could be understood by all who took the trouble to read them, and which practically, so far as concerned the technical part of the works, placed the cost beyond question. Although there was, of course, no Board of Trade connection with the present matter, he had no doubt that the Author would give some details as to the cost, made out in a similar form to that

now familiar to all engineers in England. When he stated that the total cost was $5\frac{1}{2}d.$, and that the cost of power was $\frac{3}{4}d.$, it was very difficult to understand what these figures represented, or what the difference of $4\frac{3}{4}d.$ was composed of. The total cost included a great many matters which were peculiar to electrical street-railway working. If the Author would analyse those costs for a month, or for twelve months, in something like Board of Trade form, it would add very much to the usefulness of the Paper. Dr. Kennedy.

Major-General Webber asked whether the Author had used a bond for the rails, which was now coming into considerable use on the other side of the St. George's Channel, and shown diagramatically in *Fig. 6.* It necessitated a thicker flange and a heavier rail. It gave excellent electrical connection, and almost entirely avoided any vibration of the car, in passing over the joint. It was ingenious and only costly in the respect which he had mentioned. He thought it added 12 lbs. or 13 lbs. to the rail, the flange being also thickened. Major-General Webber.

Fig. 6.

PLAN.

Mr. Llewelyn B. Atkinson said it would add to the usefulness of the Paper if information were given as to the cost of the permanent way. In recently examining some figures relating to American street-railways, and comparing them with the cost of English street-railways, for horse or steam traction, it appeared that one of the great difficulties in the capital outlay, and therefore the probable earnings in England, was that the local authorities and others insisted on a road-bed of a class which was not required in America. As had been suggested in the Paper, and mentioned by one or two of the speakers, many of the roads in America were simply sleeper roads laid on the surface, or just buried into the road, and very inexpensive. He had calculated the cost of some of those roads with concrete beds, suitable for carrying the load to be dealt with and paved as they were required to be paved in England, and it appeared to him that it was useless to compare (except in some towns) the cost of American roads with the cost which would be incurred in English roads, not only on the electrical part, but on the actual permanent way. Mr. Atkinson.

Mr. Jeremiah Head remarked that in the United States the mileage of electrical tramways was equal to between one-third and one-fourth of the total single-line mileage in England, whereas he doubted if a hundred miles of electrical tramway, all told, could be found in the United Kingdom. Five years ago there were five systems Mr. Head.

Mr. Head. in the United States in very keen competition with one another: horse-cars, steam-locomotive cars, trolley-cars, accumulator-cars, and cable-cars. All had now virtually given way to trolley-cars. That had not been done without good reason, for it should be remembered that electric railways had very great advantages. It had been stated in the Paper that they were working on gradients as steep as 1 in 8. That, so far as he knew, was quite unprecedented in any other type of adhesion railways whatever. The trolley-cars were so well under control that if the road was obstructed ahead the motor man could go along as gently as he liked, whereas if it was entirely unobstructed he could go along as quickly as 26 or 28 miles an hour. He had himself been in trolley-cars with a clear road and had timed them up to that speed. In the City of Cleveland the average speed, including stops, was 9 miles per hour, which involved a maximum between stops of about 18 miles per hour. They could stop and start with the utmost celerity; they could go round sharp curves, such as round any street corner, and they could carry a much larger number of passengers than any two-horse car or omnibus. In the United States the cars were often full, the platforms crammed front and back, with people hanging on to the side-boards on both sides. There were frequently in busy times as many as fifty or sixty passengers. By means of the electrical current the car was driven and lighted and heated; and in some cases, as in the Chicago overhead railway, a special motor worked an air-pump which was used to brake the car. He believed a little of the electrical current was also taken for working the bells. When the cars were very crowded it was difficult to indicate to the conductor a desire to stop. There were little buttons behind all the seats, and when one of them was pressed, a bell rang, and the conductor behind (who could not be seen) rang another to the motor man, and at the next street corner the car was stopped. All those were very great conveniences which were not found in any other system. He did not think there was much chance in the United States of the electrical tram-cars being superseded; there was every probability that it would extend very largely. In Philadelphia they were developing so quickly that the main-line railways were feeling the effect on their suburban traffic. A man residing in the outskirts of the city could jump into the trolley-car, at 5-minute intervals and get out at his place of business, without the loss of time that he had been accustomed to expend in walking to the railway-station, waiting for his train, and then walking from the station to his office. Although the cars did not travel quite so quickly as the main-line trains, they

were infinitely more convenient for that sort of traffic. With regard to stopping-places, the plan at present adopted was to stop at street corners and on the near side of the principal cross streets. The cars formerly stopped on the far side, but that was found to be productive of accidents on account of crossing the traffic, but now they stopped at the near side. They did not stop at intermediate places for every person who hailed them. There were, as stated by Mr. Preece, proper boards indicating the stopping places. Allusion had been made to the fact that the ordinary street traffic tended to make a rut on the inner side of the rail and cut away the concrete. The great bulk of the trolley-car rails now being made in the United States were of a different section to that shown; the lip on the upper part of the rail, instead of being hooked up as shown in the diagram, was made perfectly flat. He believed that about 75 per cent. of all the rails now made were of that form. Most of the City Councils stipulated that it should be so. The ordinary car-traffic ran on the flat place inside the rail, and that being the same gauge as that of an ordinary wagon or carriage, it facilitated the ordinary traffic, and saved the road surface generally from wear and tear. When a trolley-car was approaching carts and carriages were usually occupying the rails to some extent. The motor man sounded his gong, and the traffic cleared off before he came up to it. It had been said that tramways were not a necessity in England. He thought that that could hardly be decided till there had been a little more experience. Improved communication in any country was sure to lead to benefit. If facilities for travel were afforded they were sure to be used, and if in Great Britain electric tramways were made in populous districts, giving the people facilities to which they were at present strangers, it was quite certain that they would use them. The point with regard to cost of traction alone would prove their advantage. The London omnibus with its two horses accomplished no more than 12 miles a day per horse, and cost at least 18*s.* a week each to keep; the cost of the two horses was something like 6*d.* per mile. In the case under discussion it was stated that the cost was $\frac{3}{4}d.$ a mile for power only; that would give some idea of the saving that might be expected in places that were suitable for such a system. The great argument used in this country by persons who knew nothing about electric tramways, which he was sorry to think included the major part of the population, was that overhead wires were ugly, that the posts were ugly, and that they would never be allowed because people would not permit the disfigurement of the streets and the like. He

Mr. Head.

Mr. Head. thought, however, that it would always be found that questions of beauty and ugliness were very much what people were or were not accustomed to. Exactly the same thing had been said of the overhead electric telegraph and telephone wires in the past; but now no one took the slightest notice of them. So far, with regard to the tramway wires, certainly they might be put up in an ugly way with rough wooden poles and the like, but where they were erected artistically and the poles were made ornamental, whether placed in the middle of the street with brackets on each side, or in a line with the lamp-posts, or whether the suspending wires were stretched from house to house, nobody elsewhere took any notice of them. He only wished that some of the Town Councillors and others who had been on deputations to Bristol and a few other places in the country, would go on the other side of the Atlantic and stay there six months; nothing more would then be heard of the puerile objections to so great and successful a product of civilization, nor would any other system, such as cable-cars, be entertained for a moment in comparison with it, where there was sufficient width of street and where the locality was generally suitable.

Mr. Hedges. Mr. Killingworth Hedges desired to supplement the remarks of Mr. Head as to the great progress of electrical traction in America. It had been remarked that some of the roads were sleeper-roads. There were, no doubt, a great number of what would be called, in England, light railways, running from point to point, occasionally on the main roads; very often the land was acquired by the company, and naturally they made the road-bed in the cheapest manner. A few years ago, when he went from one side of America to the other, and visited many installations in the principal towns, he found that the principal object of the engineers was to construct the road-bed in the streets of cities in a good manner. Great pains were always taken in putting down a permanent road-bed, and using rails of very heavy section. In the early days, light-section rails were used, but that was found to be a great mistake. Many engineers had told him that the secret of their success was in putting down a rail which would not have to be taken up for a long time, or require to be examined. The rail-bonds had to be more carefully designed and proportioned than was at first expected. Light bonds were used on the early roads and found to give great trouble; but with heavy bonding and heavy rails there was much less trouble, and electrolytic action of pipes almost entirely disappeared. Overhead insulated copper wires has been referred to by the Author. He had not been in the United States for two years,

and was not, therefore, up to date, but he had thought that that system was being done away with altogether, because it was very unsightly. If it was going to be used in this country it would be an additional objection to many people who would stand a single trolley-wire, and perhaps some feeder-wires, but they would not wish to have return-wires also carried overhead. He observed that at Montreal steam power-stations were used. When he was in Canada there was a talk of employing water-power. He should like to ask if any scheme was brought forward for using the immense water-power in the neighbourhood of Montreal for generating electricity, and, if so, why it was not adopted for working the tramways mentioned in the Paper. Mr. Hedges.

Mr. G. C. Cuningham in reply to the discussion said, with regard to the tee-rail with a plank laid alongside, that when ordinary vehicles followed on the tramway line the horse naturally trotted midway between the rails, and the wheels of the vehicle in consequence ran on the plank laid alongside the rail. This prevented the rut from forming. Very little care, however, on the part of the road repairers would prevent the rut from forming, even where no plank was laid, especially where the traffic was light in suburban districts. In the suburban parts of Montreal, on the macadam roads, there was a good deal of line of the ordinary sleeper construction. The sleepers were laid at about $2\frac{1}{2}$ feet, centre to centre, and filled in with macadam to the level of the surface of the rail; the ordinary Sandberg pattern, or tee-rail, was used. In some instances a 4-inch plank was spiked down alongside the rail, so as to prevent as much as possible the cutting away of the macadam close inside the rail. That construction had been very satisfactory so far, but no doubt the more satisfactory construction was that laid with concrete. A very large amount of the street mileage of Montreal was so laid. The plan that he adopted there was to use a moderately heavy section of rail, not a very heavy section, because he relied upon the concrete to give rigidity. It was necessary to have a rail rigid, because if there was undulatory action in the rail it would act upon the paving blocks on either side, and in the winter particularly it would have a bad effect in pumping any moisture, and sudden and violent frosts would heave the paving and split it to pieces. It was considered better to rely upon the concrete to make the rail rigid rather than to have a very heavy section of rail. He was aware that in many places in the United States a very heavy section of rail was used, laid in most places upon a gravel foundation, which he thought was not as good as the plan adopted, because in the case of concrete Mr. Cuningham.

Mr. Cuningham.

there was a solid foundation bearing the whole length of the rail, and it was impossible for any spring to take place.

In reply to the various remarks that had been made as to the power used on the system, he submitted a Table (p. 305) showing in detail a summary of the working of the power-house for the year ending 30th September, 1895. The amount of power used could best be derived from the number of watt-hours used per motor-car hour. The average was 14,851 watt-hours, or almost exactly 20 HP.-hours. This power would be affected by the weight of the motor-cars and the weight of passengers and trailers which they conveyed; and therefore, to reduce this to a proper basis for comparison with other systems, it would be necessary to know what this power corresponded to in watts or watt-hours per ton-mile. The Table showed that the number of watt-hours per ton-mile was 282 (= 0·38 HP.), and the number of watts 2,290 (= 3·07 HP.), the speed of the car being 8·12 minutes to a mile. This was the power recorded at the terminals of the generators, and included all losses on the line. In other words, in order to move a ton a mile on the Montreal system the power-house had to exert a force of 3·07 HP. On other systems where the gradients were less severe and where the obstructions of winter were not so serious, the power used would naturally be less. In Toronto, for instance, where the streets were very level, about 30 per cent. less power was used than in Montreal. The power in Montreal varied between a maximum of 2,716 watts per ton-mile in winter and a minimum of 2,048 watts in summer.

From the "watts per ton" had been estimated the average draw-bar pull per ton. This was found to be 19·2 lbs. Instead of working from this draw-bar pull as the basis and deriving the total power of the station, the process had been reversed, and from the total power exerted in the station worked down to the average draw-bar pull. In this was included whatever power might be lost in transmission. Great care had been taken during the past year, and covering the period dealt with by the Paper, to perfect the feed-wire and return-wire system and to improve the bonding, so as to reduce losses as much as possible. The loss from leakage was absolutely nil, the whole system having been recently (1896) carefully tested with the most delicate instruments by the city electrician with a view to determining leakage. The consequence of this was that the power now generated in the power-house per ton-mile was less than in 1894–5, and though the cost of haulage for that year (less than $\frac{3}{4}d.$ per car-mile) seemed to be particularly small, the cost for the present year (1895–6) would be lower still.

Mr. Cuningham.

With reference to the unsightliness of the overhead trolley system, he might mention that he had seen that day in Edinburgh, the system adopted there for the electric-lighting of that city. Large iron poles had been erected on either side of the street with brackets projecting, from which the arc-lamps depended. It would

TABLE SHOWING WORK DEVELOPED AND COAL CONSUMED ON MONTREAL STREET-RAILWAY SYSTEM DURING YEAR ENDING 30TH SEPTEMBER, 1895.

Motor car-miles	5,677,581	
Trailer car-miles	654,057	
Total car-miles	6,331,638	
Motor [1] ton-miles [2]	36,900,873	
Trailer [3] ton-miles	1,645,140	
Passenger [4] ton-miles	1,810,033	
Total ton-miles	40,356,046	
Passengers carried	25,857,758	
,, ,, per car-mile	4·10	
Coal consumed	19,171·60	tons.
,, ,, per car-mile	6·80	lbs.
,, ,, ,, motor car-mile	7·50	,,
,, ,, ,, ton-mile	1·06	,,
,, ,, ,, passenger-mile	1·63	,,
,, ,, ,, E.HP.-hour	2·80	,,
Engine-hours	25,183	
Electrical output	15,305,254	HP.-hours.
,, ,, per engine-hour	608	,,
,, ,, ,, motor car-mile	2,011	watt-hours.
,, ,, ,, ton-mile	282	,,
,, ,, ,, lb. of coal	266	,,
Motor Cars. Total on road	43,822·00	
Average per day	120·07	
Car-hours	68,837·00	
Speed	7·39	miles per hour.
,,	8·12	minutes per mile.
Watt-hours per car-hour	14,851·00	
,, ,, mile	2,011·00	
Watts per mile	16,329·00	
,, ton	2,290·00	
Ton-miles per car-mile	7·11	
Effort per ton per mile	101,316·00	foot-lbs.

be the simplest thing in the world to erect similar poles on the opposite side of the street and span a wire across; then they would have all that was necessary for overhead wires. The iron poles erected in Edinburgh were by no means unsightly. Electric

[1] Weight, 6 tons.
[2] 2,000 lbs. to 1 ton.
[3] Weight, 2½ tons.
[4] 140 lbs. each.

Mr. Cunningham. light enormously improved the appearance of the city, and it was in every way satisfactory. Certainly no one complained of the unsightliness of the poles. He was well aware that in this country there was a strong objection to overhead wires. So there was in Canada, but within a fortnight after they had been erected there was not a man in the city who wished to have them taken down, the benefit of the system being so apparent. Reference had been made to insulated return-wires. It would be a simple matter to bring back the return-wires underground just as the feed-wires might be taken underground, but in Montreal that refinement had not been considered necessary.

A question had been asked as to the use of water-power in Montreal. Great progress had been made with the use of water-power there, but considerable difficulty was felt with regard to it on account of the ice in winter. The ice jammed in the river in the winter and raised the level of the water so that the head available in the summer was much reduced. It was doubtful if the power could be used all the year round, and consequently the Street-Railway Company had been forced to rely upon steam-plant. Even if water-power were installed, it would not be prudent to throw away the steam-plant until it had been tested for some years. The ice-jam did not form every year in the way of raising the water.

Correspondence.

Mr. Moss. Mr. Lincoln Moss, of New York, thought the Paper described an excellent example of modern electric railway construction, although it was to be regretted that the direct-coupled type of multipolar generator and engine had not been used in place of belted machines. He differed from the Author as to the waste of energy in the steam locomotive. On American elevated roads, a passenger ton-mile was covered with a consumption of between 4 ozs. and 8 ozs. of coal, including braking and all losses, with trains weighing between 80 tons and 130 tons, moving at an average speed of 15 miles per hour, stopping four times per mile, and over gradients of as much as 2 per cent. If more elevated roads should be built, it was probable that the steam locomotive must give way to the electric-motor car, in view of the recent successes of heavy electric traction. In elevated service electric-motor cars would reduce the train weight, decrease the live load on the structures, and greatly increase the available draw-bar pull, which will give a decided increase in speed, reduce the number of coaches required, and the number of train-

men required. It was not expected that the quantity of coal now burned would be reduced by the steam locomotives, but the quality and price would be very much lower. The experience gained in the United States in the use of triple-expansion engines for electric-railway work had been so unsatisfactory that he took exception to the Author's opinion that "there is no reason why triple- and quadruple-expansion engines should not be used in a power house, and a still further economy thereby effected." It had been found in such efforts that a positive loss occurred; in some cases triple-expansion engines had consumed more coal per HP.-hour than a simple engine. This was entirely due to the fact that the load was unsteady and constantly fluctuating. To obtain good results the engine-units must be so small that the load could be subdivided economically and a fairly good cut-off range maintained on each engine. He had seen compound engines of 1,000 HP. and 2,000 HP. driving dynamos when the low-pressure cylinder acted simply as a brake, receiving so little steam as to have no cushion at all, causing a pounding and destructive wear. In one of the largest American street-railway systems, operating many engines of various types, the best record for economy in fuel consumption was held by a set of simple four-valve (gridiron) engines. From an operating standpoint it was very desirable to have a moderate steam-pressure on the boilers, pipes and valves, and the investment was far lower than it would be for a triple-expansion plant. He considered that the best American plants were those using direct-coupled four-valve engines, worked compound condensing, with steam-pressure not exceeding 140 lbs. per square inch. The Scotch boilers were not excelled in economy, space required, reserve power and dryness of steam. Mr. Moss.

Mr. O. F. Nichols remarked that the action of concentrated wheel-loads, often exceeding 5,000 lbs., had not been provided for in the earlier lines, and much outlay had been necessary on vexatious repairs to the road-bed in the development of a more stable track. The girder-rail had finally come to be essential on such lines, and the use of a continuous bed of good concrete under a broad-footed girder-rail, although now confined, as the Author said, to the cities of Toronto and Montreal, would no doubt extend and be generally accepted as furnishing the only adequate foundation for electric street-railways, at the same time permitting the most permanent roadway outside the rails. To American railway engineers the most interesting feature of the Montreal lines was, perhaps, the onerous conditions imposed by the lease, especially when taken into account with the financial results obtained from Mr. Nichols.

Mr. Nichols. operation. Notwithstanding that the maximum fare was to be 5 cents and include transfer over the whole system; that tickets were to be sold at six for 25 cents at all times and at eight for 25 cents for certain hours, and that the company was to pay 4 per cent. of its gross earnings annually to the City, the operating expenses had steadily decreased from 82 per cent. with horses to about 59 per cent. with electricity. The number of passengers per mile of single line had increased in the meantime but 20 per cent., while the net earnings per mile of single track had nearly trebled, and realized in 1895 5 per cent. on a capital of nearly $130,000 per mile. This result was quite phenomenal, and indicated an excellence of management rarely equalled on electrical lines, and certainly remarkable when the conditions of construction and of climate were so exacting as in Montreal. The result of change in motive-power from horses to electricity in the United States had generally been to reduce the working expenses from about 80 per cent. to about 65 per cent. The gain in traffic had generally been greater than in Montreal, while the net earnings had not generally exceeded those shown in the Paper.

Mr. Snell. Mr. Albion T. Snell supposed, with regard to the Author's statement that "each dynamo has three cables—one for the positive, one for the negative, and the third as an equalizer"—that the dynamos were designed to give each one-half of the working pressure, say 275 volts, and were placed in series of two with an equalizing wire between them. Comparing this Canadian tramway with those in the United Kingdom, it was curious to notice how the number of passengers carried per car-mile affected the possible earnings of the companies. For example, the Canadian tramway averaged four passengers per car-mile, with an average fare of 2·5*d.* In the United Kingdom, since the fares did not average much more than 1·25*d.*, it was necessary to carry twice as many passengers in order to earn the same dividend, even if the working costs were the same. This had an important bearing on the introduction of electric tramways in this country, and should not be lost sight of in making comparisons with American lines.

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25 February, 1896.

Sir BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The discussion upon "The Electric Street-Railway System of Montreal, Canada," occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2858.*)

"The Reconstruction and Widening of Barnes Bridge, L. & S. W. Ry."

By Alfred Weeks Szlumper, M. Inst. C.E.

Barnes Bridge was one of the largest of the cast-iron bridges on the London and South Western Railway, all of which have for some years past been undergoing reconstruction and strengthening. It carried the loop-line between Barnes and Feltham over the River Thames, and consisted of three openings, with an arch in brickwork on the Surrey side over Barnes Terrace, its total length being 450 feet. The openings over the river were of cast-iron ribs, each 120 feet span, with a versed sine of 12 feet. They were of 2-inch metal, 3 feet deep, with 12-inch flanges, the horizontal member being supported by ornamental spandrel standards over the haunches. The ribs were fixed into iron skewbacks, or shoes, at each bearing, and were constructed in six sections. Each opening consisted of four such ribs, two carrying a line of way and parapet. The superstructure was of timber joists, about 3 feet apart, and longitudinals with 3-inch decking. The parapet was of cast-iron, and was bolted to the outside ribs. The bridge was built about forty years ago, by Messrs. Brassey, from the designs of the late Mr. Joseph Locke, Past-President Inst. C.E. An extensive system of wrought-iron bracing to all the ribs was subsequently inserted, and an apron of sheeting-piles and bags of concrete was built around each pier to arrest the scour produced by the strong current in the river at this spot.

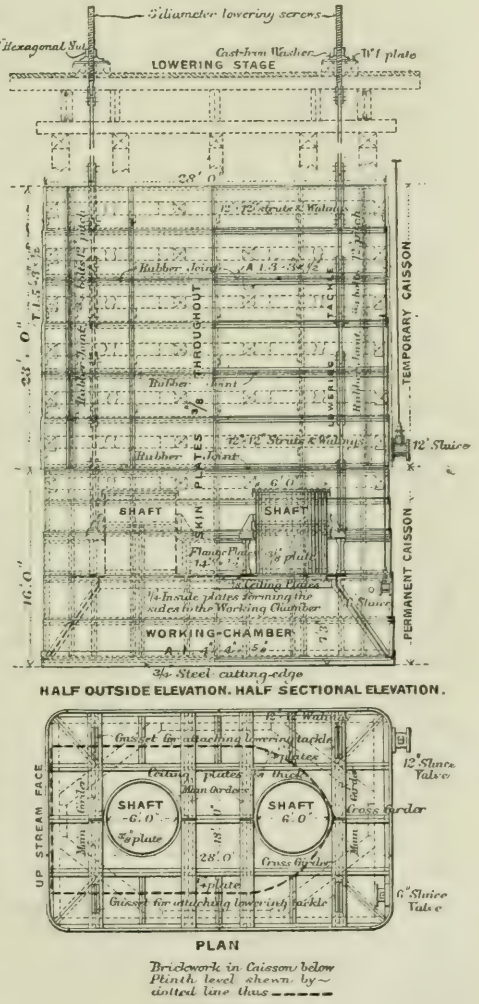
In 1891 it was decided to proceed with the reconstruction of the bridge, simultaneously with the widening rendered necessary in connection with the railway between Barnes and Chiswick. The piers and abutments of the old bridge, of brickwork faced with Bramley Fall stone, have been lengthened 27 feet above the cutwaters, and 34 feet respectively. The bridge has been widened sufficiently to accommodate three lines of way; and a public footway, approached by staircases on each bank of the river, has been added. Borings disclosed London clay at a

depth of about 16 inches below the bed of the river, overlain, on the site of the abutments, by a bed of alluvial gravel and sand.

Abutments.—The foundations for the abutments were inserted by ordinary cofferdams, and to connect the new brickwork with the old, a vertical chase was cut in the latter. The cofferdams consisted of a single row of 14-inch pitch-pine piles, sawn square, and driven to a depth of 12 inches below the level of the bottom of the excavations, at a distance of 8 feet in front of the concrete, in the Middlesex abutment, and about half that amount in the Surrey abutment. The pile-shoes were of the ordinary sheeting-shoe pattern, weighing 82 lbs. each, with a solid cast-iron point, and were secured to the pile by wrought-iron straps and spikes. The piles were driven by a Lacour steam pile-driver having a 25-cwt. monkey, at an average rate of three piles per hour when in full working order. The flank of the cofferdams was made good to the abutments by a 16-inch timber cut to the curved batter of the face and bolted to the brickwork, a tapered closing pile being then driven in the flank and the joint between the shaped pile and the brickwork being grouted with neat cement. A trench was excavated to the bottom of the old concrete and against the last pile, 3 feet wide, and extending 12 inches in front of the concrete; this was filled with clay puddle to make a watertight joint. A sluice, 15 inches square, constructed of 2-inch elm, was inserted in the face of the dam at the level of the bed of the river, and a sump 5 feet square was excavated to a level of 2 feet below the bottom of the foundations. Where necessary the joints between the piles were caulked with tarred oakum. To permit of future dredging operations and to protect them from scour, the abutments were founded in the London clay at a depth of 24 feet below the surface. To secure the old abutments the whole of the trench was lined with 2-inch runners. The main struts were of fir, 12 inches square, placed 8 feet apart, the walings being 12 inches by 6 inches and the props 8 inches square. Although little water percolated through the cofferdams, a considerable volume of land-water from the gravel was encountered; this was conveyed to the sump and pumped out by a 4-inch steam bucket-pump. The concrete used for all the foundations was composed of Thames ballast and Portland cement in the ratio of 5 to 1. The old abutments were underpinned at the junction with the new work where necessary. The whole of the Middlesex abutment cofferdam was removed when the brickwork was completed; but in the Surrey cofferdam, the piles forming the face of the dam

were left in, sawn off at the level of the bed of the river, excepting a pile every 8 feet which subsequently formed the supports for the towing path. The piles to the Middlesex abutment cofferdam and staging were drawn by hand-power, a powerful hand-winch, manned by from four to six men, and heavy chain tackle being used. Those forming the Surrey abutment and pier staging were removed by a 50-ton hydraulic jack.

Figs. 1.



Piers. — The pier-foundations were built by the aid of wrought-iron caissons; as it was thought that the vibration caused by driving piles 15 feet or 20 feet into the London clay, if cofferdams had been used in the vicinity of the old piers, might have been dangerous to the old ribs. There might also have been some difficulty in making good the cofferdam to the old piers. A considerable amount of pumping would probably have been necessary, and this would have had a tendency to cause settlement in the old bridge, the foundations of which were of uncertain depth. If a blow occurred the old structure would have been endangered. Caissons presented none of these disadvantages, and they were so designed that, if necessary,

compressed air could be used. The necessity for this, however, did not arise. The caissons, *Figs. 1*, consisted of two parts, the lower portion permanent, 28 feet by 18 feet by 16 feet deep, and the upper portion temporary, 28 feet by 18 feet by 23 feet deep, the junction between the two being arranged at the level of the bed of the river. The top of the temporary caisson reached to spring-tide level, about 3 feet above ordinary H.W.M., when the permanent caisson was completely sunk. A floor was fixed on the stiffening girders in the permanent caisson 7 feet 3 inches from the cutting-edge, the space below forming the working-chamber, access to which was obtained by means of two shafts, each 6 feet in diameter, piercing the floor and extending to within 1 foot 6 inches of the top of the permanent caisson. Immediately above this floor a series of cells were built, and as the caisson was lowered concrete was placed in them for kentledge. In the skin of the permanent and temporary caissons, a 6-inch and a 12-inch sluice respectively were fixed. Watertight joints were secured by the insertion of a continuous washer of indiarubber 4 inches by $\frac{3}{4}$ inch between the different sections. The caissons were erected upon a temporary staging immediately over their permanent position and were lowered by the aid of four sets of lowering-links, terminating in 3-inch screws and 6-inch nuts, turned by large spanners. The bed of the river was prepared by divers to receive the caisson, and the average rate of descent after the caissons were sealed was 15 inches per day. A 6-inch donkey-pump was found sufficient to deal with the water until the sluices were permanently closed and the water pumped out, after which the excavations were entirely free from water. A few beds of septaria, varying in depth between 6 inches and 12 inches, were met with, and it became necessary to remove the nodules beneath the cutting-edge. The total weight of concrete placed in the cells in the Middlesex pier caisson to overcome skin-friction was 80 tons, and in the Surrey pier caisson 148 tons, the former giving friction of 2·03 cwt. per square foot and the latter 2·95 cwt. A depth of 16 feet below the bed of the river having been reached, the remainder of the permanent concrete was placed in the caisson. The timber strutting was inserted as the lowering proceeded, seven frames of timber being used, about 3 feet 9 inches apart vertically; the whole of the timber was 12 inches square fir. As the brickwork and masonry proceeded the timber struts were struck at low water, a new series of short struts with walings against the new work, when sufficiently set with "soldiers" against the main walings, being put in.

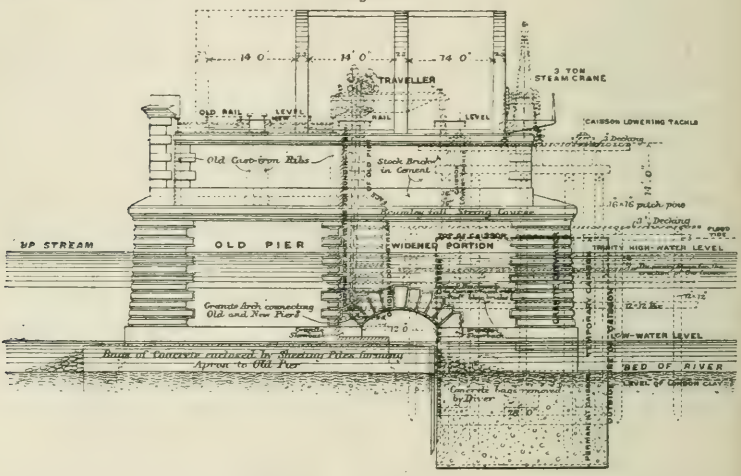
The up-stream ends of the new piers were built about 8 feet from the cutwater to the old piers; this enabled the new work to be erected without in any way interfering with or endangering the foundations of the old piers. A granite arch, of 12 feet span and 4 feet thick, was built connecting the old and new piers, *Figs. 2* and *3;* the springing level being 2 feet 3 inches above low-water level. The skewback, also of granite, consisted in each case of two stones only, and those in the caisson being in position, the brickwork and granite cutwater was finished to T.H.W. level; and, a toothing having been left in the up-stream face of the brickwork in line with the back of the skewback, the up-stream end of the temporary caisson was removed. Meanwhile, the down-stream end of the old pier was cut away to a point close to the outside cast-iron rib down to the level of the bed of the new skewback; this was now set in position and the centering, consisting of four strong timber ribs and 2½-inch lagging, was erected. The granite connecting arch was then built, two strips of 7 lb. lead, 2½ inches wide, being laid between the bed joints of each voussoir, the face joints being pointed in a quick-setting Portland cement and then run in with Portland-cement grout, 2 of washed sand to 1 of cement. The skewbacks and arches were built by an overhead traveller erected between the high-level stage and the outside cast-iron rib. The connecting arch and the brickwork above it to T.H.W.M. were built as tide work.

The brickwork of the abutments and piers was of best London stocks in Portland-cement mortar, in the ratio of 2 of Thames sand to 1 of cement, faced with Staffordshire blue bricks up to the first string course. This string was of Bramley Fall stone 2 feet deep, and above it the work consists of stock brickwork, also in cement mortar, with a top string course similar to the lower one. The cutwaters of the piers are built of Cornish granite in 18-inch courses capped by an apron in Bramley Fall stone. The bed-stones are also of Cornish granite, 5 feet by 4 feet by 2 feet 6 inches, set back 9 inches from the face of the brickwork. The steam-crane placed on the high-level stage delivered all the material for building the piers, excepting the granite connecting arches and skewbacks. The total weight, including the superstructure placed upon the foundations of the piers, is approximately 3½ tons per square foot.

During the cutting down of the old piers, the setting of the skewbacks, and the building of the connection between the new and old piers to the first string course, a period of seven weeks, single-line working was established over the bridge, under the

electric train-tablet system. A permanent signal-box exists on the Surrey side of the bridge, and a temporary one was erected on the Middlesex side, switches being placed in the down line near each box. The work could be carried on at one pier at a time only; this of course nearly doubled the time occupied, but the advantage was gained that the same temporary caisson was available for both piers. The staging in the river was kept within the smallest limits, viz., about 470 square yards to each pier, and of this, cement and material sheds occupied an area of 64 yards. It was built with fir piles, 12 inches square, driven, at distances of 9 feet apart, to a depth of between 6 feet and 10 feet into the bed of the river.

Fig. 2



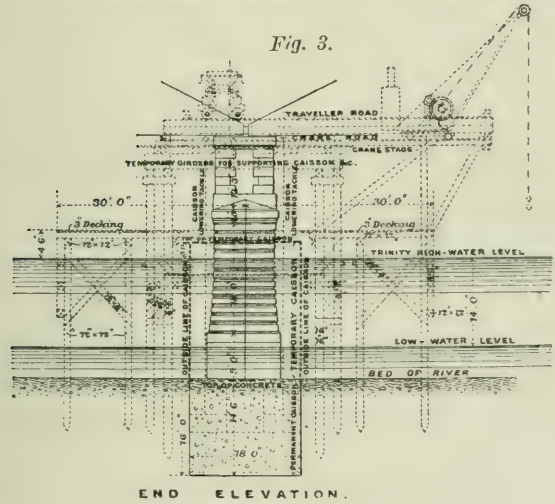
FRONT ELEVATION

Scale, 32 feet to 1 inch.

In the case of the Middlesex pier staging, the piles were drawn by a wreck raiser or "samson," belonging to the Thames Conservancy. This craft is 70 feet in length, and 24 feet beam, its tonnage being 150. It is fitted with powerful steam-winches actuated by a 12-HP. winding-engine. Three strong davits project over the bows, accommodating a 6-inch steel hawser connected to the winding-drum by heavy chain luff-tackle. A 2-inch iron sling-chain was placed loosely around the pile to be withdrawn at the level of the water, and the steel hawser was then made fast to it and slackened out, to allow the sling to drop to the bed of the river. The winding engine was then set in motion and the pile was quickly drawn. In some cases, however,

the winding continued until the bulwarks of the craft touched the water-level, the tension which was then exerted amounting to about 50 tons. The average power required, however, was between 25 tons and 30 tons. The piles were removed at the average rate of three per hour by this craft, but it could not be economically employed where there was, at low tide, a smaller depth of water than her draught, as she could only be worked when afloat. In accordance with the requirements of the Thames Conservancy, twelve of the cluster piles close to the skin of the caisson were cut off 6 feet below low-water level, which varied between 12 inches and 24 inches below the bed of the river. This necessitated dredging a small trench in front of the pile for

Fig. 3.



END ELEVATION.

Scale, 32 feet to 1 inch.

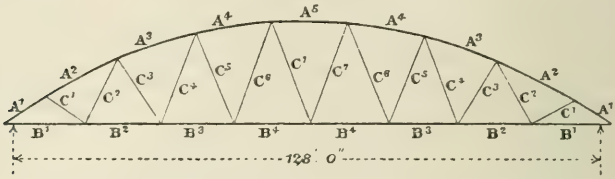
the diver to work in; five holes were bored through the pile with a 2-inch auger at the level required, a rope being then made fast to the top of the pile which was pulled over by a hand-winch.

The total cost of the cofferdams, caissons, staging, pumping and other temporary works was £8,742; the average cost per foot run of the cofferdams, including the temporary staging in the river, and removal of the same, also pumping, was £17; omitting the temporary staging and pumping, the cost was £11 10*s.* per foot run.

Girders.—The main girders are of the single-braced bowstring type, 129 feet 4 inches in length, the bracing being arranged in eight bays. The booms are 2 feet 3 inches wide, the top one being built to a radius of 112 feet 5 inches, with a versed sine of

20 feet. The girders are placed 16 feet 3 inches from centre to centre, and the superstructure consists of a corrugated wrought-iron flooring, 9 inches deep and $\frac{1}{2}$ inch in thickness. The public footway, 8 feet wide, on the down-stream face of the bridge, is carried on cantilevers fixed to the bottom booms of the main girders. The principal resulting stresses in the main girders, *Fig. 4*, were calculated for an effective span of 128 feet, with a depth of girder in the centre of 20 feet, the distributed rolling

Fig. 4.



and dead loads being respectively 211·8 tons and 104·2 tons. The total stresses in tons are as shown in the following Table :—

Upper boom.	A^1		A^2	A^3	A^4		A^5
+	260·8		278·0	264·1	259·1		257·7
Lower boom.	B^1		B^2		B^3		B^4
−	219·9		237·7		246·1		249·0
Bracing.	C^1	C^2	C^3	C^4	C^5	C^6	C^7
−	36·1	35·5	38·8	37·6	42·5	40·7	42·8
+	..	3·5	2·3	14·0	9·5	16·6	14·6

The moment of inertia of the corrugated flooring is given by

$$I = 2\int_{\frac{D}{2}-2t}^{\frac{D}{2}} B\,x^2\,dx + 2\int_{o}^{\frac{D}{2}-t} t\sec\theta\,x^2\,dx,$$

where D = depth over all = 9 inches.
t = thickness = $\frac{1}{2}$ inch for each plate.
B = breadth deducting rivet holes.
θ = angle of slope of side of trough = 30°.

Therefore

$$I = 2\times\left(\frac{6\cdot75-1\cdot75}{3}\right)\times(4\cdot5^3-3\cdot5^3)+\frac{2\sec 30^\circ}{3}\times 4^3$$

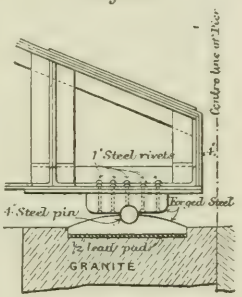
$$=\frac{482\cdot5}{3}+\frac{2\cdot31\times 64}{3}=210.$$

The moment of resistance $=\frac{210\times 5}{4\cdot5}=233$ inch-tons.

Now the greatest concentrated load to be sustained by the flooring is 18 tons on a pair of driving-wheels. Assuming this load to be distributed over only three bays of flooring, the bending moment at the centre of one bay would be $3 \times 54 = 162$ tons. The moment of resistance of 233 inch-tons, therefore, leaves a safe margin. The actual deflection measured under a passing engine with 18 tons on the driving-wheels was $\frac{5}{32}$ inch; the load required to produce this is found to be 1·8 ton, showing the weight to be distributed over five bays of the flooring.

Bearings.—The bearings on the Middlesex abutment and Surrey pier, *Fig. 5*, are fixed, those on the Surrey abutment and Middlesex pier, *Figs. 6*, being movable. The efficiency of the ordinary roller-bearing is open to considerable doubt; in some railway bridges where such bearings are in use, there is little or no evidence of any movement of the rollers—probably the result of their becoming clogged by the accumulation of rust, dirt, &c.; moreover, the bearing-blocks, which are usually made of cast-iron, are not unfrequently found to be cracked. The method adopted at Barnes is one designed to obviate these defects. All bearings are "hinged" or pivoted on steel pins, and instead of cast-iron, the bearing-blocks are of forged steel. The distance between the centres of the steel pins of each girder is 126 feet 4 inches. An upper block, 1 foot 8 inches by 3 feet by $4\frac{3}{4}$ inches, is riveted to the ends of all the girders, and in the case of the fixed bearings, *Fig. 5*, a corresponding lower block, but 2 feet 6 inches by 3 feet by $4\frac{3}{4}$ inches in the centre, tapering off to 2 inches at the ends, is placed upon a $\frac{1}{2}$-inch lead pad in a recess on the granite bed-stone. Between this upper and the lower bearing-blocks is fixed a 4-inch steel pin or pivot, the hole to accommodate this pin being bored half in each block.

Fig. 5.



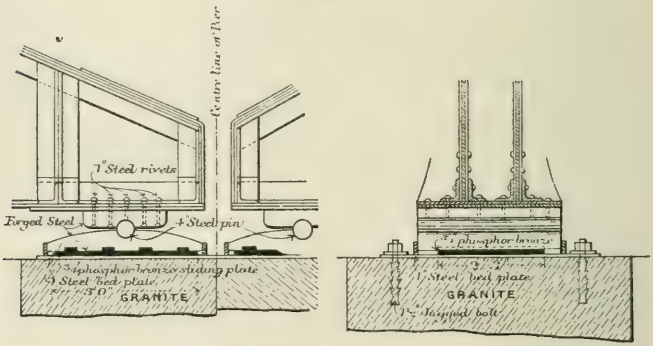
Scale, ¼ inch to 1 foot.

In the case of the movable or expansion bearings, *Figs. 6*, the lower block is 3 feet 3 inches by 3 feet by 6 inches in the centre, tapering off to 2 inches at the ends; four grooves are formed in the lower surface at right angles to the centre line of the main girder, and a phosphor-bronze sliding-plate, 3 feet by 2 feet 3 inches by $\frac{3}{4}$ inch, is placed under this block, being held in position by four projections or ribs formed on the upper surface of the plate fitting into the grooves under the bearing-block. This phosphor-bronze plate slides upon a steel plate, 4 feet 6 inches by 3 feet 8 inches

by 1 inch, fixed to the top of the granite bed-stones by lewis bolts. In order to prevent dust and dirt from getting under the phosphor-bronze sliding-plate, a strip of gun-metal, 3 inches by 1 inch, is bolted to the edges and sides of the lower bearing-block projecting down to the steel plate. The steel bearing-blocks and the phosphor-bronze plate are machined on all surfaces, and before being placed in position the sliding surfaces were well oiled. These expansion bearings are very sensitive.

Erection of Ironwork.—The whole of the ironwork was delivered by barges alongside the abutments and was unloaded on to the widened portion of the embankment on both sides of the river, the main girders in sections of maximum weight of 5 tons. The girders spanning the side openings of the widened portion of the bridge were put together and riveted on this embankment and then

Figs. 6.



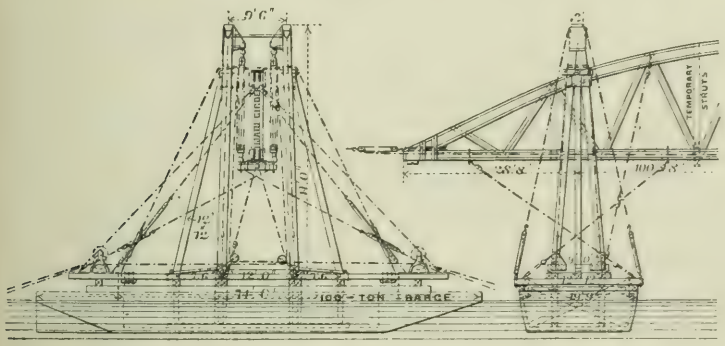
Scale, $\frac{1}{4}$ inch to 1 foot.

floated out into position; those for the central opening were erected and riveted on these side openings after the corrugated flooring was in place, being afterwards floated out into position similarly to the side openings. The girders on the old portion of the bridge were erected in position.

Floating the Girders into Position.—The riveting being completed, the timber-blocks were removed and the girder lowered on to two pairs of 8-inch by 6-inch rolled-iron joists, one pair at the land end and the other 42 feet from the opposite end, bearing upon a temporary line of railway metals consisting of three rows of rails. Two pairs of raking struts of timber were then inserted near the centre of the girder, and steel-wire guys were made fast to the top boom to steady it. A $2\frac{1}{4}$-inch steel hawser was made fast to the front of the main girder and returned to a steam-winch, the bight passing

through a snatch-block held in position by a $3\frac{1}{4}$-inch steel hawser anchored on the opposite side of the river; a check-rope secured to the back end of the girder was controlled by a steam-crane, and 5 tons of kentledge were placed on this end of the girder. All being ready for launching the girder, the steam-winch was set in motion moving it about 40 feet forward over the abutment. A timber derrick erected upon a 100-ton barge, *Figs. 7*, was now floated into position under the girder to a point 29 feet from the projecting end, and was secured to the girder by a rolled-iron joist saddle suspended from the derrick by strong tackle, being placed at such a level that at the next tide the weight of the girder would be taken by this derrick. To control the movement of the barge, heavy ship anchors were placed above and below the bridge; and 7-inch cables were made fast to them,

Figs. 7.



Scale, 32 feet to 1 inch.

terminating in luff-tackle and worked by hand-winches on the barge. Between the two tides guy-ropes were disposed about the girder at various points and made fast to the barge so as to control its position; the last operation being to remove the kentledge and the front pair of rolled-iron joists and to secure the girder to the saddle and derrick. As soon as the barge took up the weight of the girder by the rising tide, a start was made for the pier by setting the steam-winch in motion at a very slow rate, and striking the land end of the girders with heavy sledge hammers, hauling in the front anchor cables and slacking out those in the rear on the barge. A heavy plumb-bob was suspended from the top of the derrick to the deck of the barge, and any tendency to list was immediately counteracted by hauling on or slackening out on the guy-ropes. About one hour before high tide was the moment selected for the start, so as to insure ample time to reach the pier prior

to ebb tide setting in, and the average time taken in the actual floating out was twenty-five minutes. Having reached the pier, the girder was lowered on to the steel pins and adjusted in position, the tackle suspending the saddle terminating on hand-winches provided for this purpose. The falling tide, too, assisted this operation. At the following high tide the derrick was floated away, the necessity of lowering the inside pair of legs, so as to clear the girder, delaying the floating away until that time. Temporary struts were placed between the new girder and the outside cast-iron rib, so as to steady the former until the next girder was floated out and the corrugated flooring and wind-ties placed in position. All the main girders on the widened portion of the bridge were placed in position in this manner, and costly temporary staging in the river was entirely avoided. The requests made by the Thames Conservancy in regard to the number and size of the openings, if such staging was used, led the ironwork contractors to adopt this method, which proved a complete success and was carried out without the least mishap.

The ironwork on the widened portion of the bridge having been completed, the up line was diverted on to this new portion, and the erection of the next adjoining bay commenced. The main girders were built on the decking of the old bridge immediately over but 3 feet above the level of their permanent positions. Temporary balks of timber were placed between these new girders and the inside girders on the widened portion of the bridge, and the old cast-iron ribs on the down-stream face of the old bridge were secured to them. The work of removing the timber cross-girders, unbolting the joints, and cutting away the ties and struts, was now commenced. One span only at a time was dealt with, each section of the rib being lowered into a barge below, and subsequently taken to Nine Elms scrap heap. As soon as the old ribs were interfered with, it was considered desirable to close the old bridge to railway traffic, and single-line working was established over the widened portion of the bridge. Meanwhile, the work of cutting away and rebuilding the old abutments and piers above springing level, to take the new girders, proceeded; the girders were then lowered on to their bearings and the corrugated flooring was fixed in position. This second bay of ironwork being finished, double-line working was re-established, the new bay accommodating the down line.

Permanent Way.—The permanent way, consisting of 87-lb. bull-headed rails and chairs, is carried upon 16-inch by 8-inch pitch-pine longitudinals, secured to the summits of the corrugated flooring by angle-iron lugs and coach screws; transomes 8 inches

by 6 inches and $\frac{7}{8}$-inch tie-bolts being fixed every 8 feet. A timber wheel-guard, 14 inches square, also of pitch pine, is placed against each longitudinal, and is held in position by holding-down bolts through the flooring.

Quality of Iron and Steel.—The wrought-iron plates were specified to stand a tensile stress of 21 tons per square inch of original section with the fibre, with a contraction of fractured area of not less than 10 per cent., and 18 tons against the fibre, with a contraction of not less than 3 per cent. Angle-bars and T-irons were required to stand a tensile stress of 22 tons per square inch before fracture, with a contraction of fractured area of not less than 12 per cent., and iron for rivets, bolts, &c., 24 tons before fracture, with a contraction of not less than 20 per cent. Steel was specified to stand, either with or against the fibre, a tensile stress of not less than 27 tons, or more than 31 tons per square inch of original sectional area, with an elongation of 20 per cent. in a length of 10 inches.

Tests.—The structure was tested with stationary loads placed upon the centres of the spans, as well as with loads moving over them at speed. The results are given in the appended Table:—

Girders.	Test No. 1.		Test No. 2.		Test No. 3.		Permanent Set.
	Load (Stationary).	Deflection.	Load (Stationary).	Deflection.	Load (Moving).	Deflection.	
Down-stream—	Tons.	Inch.	Tons.	Inch.	Tons.	Inch.	Inch.
Surrey span . .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Centre ,, . .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Middlesex span .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Up-stream—							
Surrey span . .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	0
Centre ,, . .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	$\frac{1}{32}$
Middlesex span .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	$\frac{1}{32}$
Centre—							
Surrey span . .	220[2]	$\frac{3}{8}$	440[4]	$\frac{7}{16}$	440[4]	$\frac{7}{16}$[7]	0
Centre ,, . .	220[2]	$\frac{3}{8}$	440[4]	$\frac{7}{16}$	440[4]	$\frac{7}{16}$[7]	$\frac{1}{32}$
Middlesex span .	220[2]	$\frac{3}{8}$	440[4]	$\frac{7}{16}$	440[4]	$\frac{7}{16}$[7]	$\frac{1}{32}$
Corrugated flooring (clear span 14 feet) . . .	..	..	..	..	18	$\frac{5}{32}$	0

[1] Two bogie tank-engines; wheel-base 61 feet 10 inches; weight on pair of driving-wheels, 18 tons.

[2] Four bogie tank-engines; two on each line of way.

[3] Four bogie tank-engines; wheel-base 132 feet 3 inches; weight on pair of driving-wheels, 18 tons.

[4] Eight bogie tank-engines; four on each line of way.

[5] Lateral movement on bottom boom, about $\frac{3}{32}$ inch.

[6] Vibration in struts but slight.

[7] Movement on expansion-bearings between $\frac{1}{16}$ inch and $\frac{1}{8}$ inch.

The consulting engineer of the railway company was Mr. W. R. Galbraith, M. Inst. C.E. The chief engineer was Mr. Edmund Andrews, M. Inst. C.E., by whom the works were designed, the Author acting as resident engineer in charge.

The Paper is accompanied by five sheets of tracings and six photographs, from which the *Figs.* in the text have been prepared.

APPENDIX.

SCHEDULE OF COSTS OF PRINCIPAL ITEMS.

	£	s.	d.
Fir in piles . . . . . per cubic foot	0	1	3
Pitch-pine piles . . . . . „ „	0	2	0
Preparing and driving piles . . . . . per foot driven	0	1	9
Pile-shoes, bolts, dogs, &c. . . . . per pound	0	0	3
Drawing piles . . . . . each	0	12	0
Cutting off piles below low water . . . . . „	0	15	0
Wrought-iron in caissons, put together . . . per ton	18	0	0
Lowering caissons into position . . . . . „	10	0	0
Excavation in river-bed within cofferdams or caissons, and remove to a shoot provided by railway company (close to work) . . . . . per cubic yard	0	9	6
Pumping by steam pump . . . . . per hour	0	6	0
Concrete in foundations in Portland cement 5 to 1 per cubic yard	0	15	0
Stock brickwork in cement, including all labour below T.H.W.M., per cubic yard	1	13	6
Stock brickwork in cement, including all labour above T.H.W.M., per cubic yard	1	10	6
Cornish granite (not including labour) . per cubic foot	0	6	6
Diver, with dress and all apparatus and one attendant per hour	0	12	0
Wrought-iron in bowstring girders, fixed complete per ton	14	0	0
Wrought-iron in corrugated flooring. . . . . „	13	10	0
Forged steel. . . . . „	24	0	0
½-inch curved plates . . . . . „	12	0	0

(Paper No. 2880.)

"Low-Level Bridges in Queensland."

By Alfred Barton Brady, M. Inst. C.E.

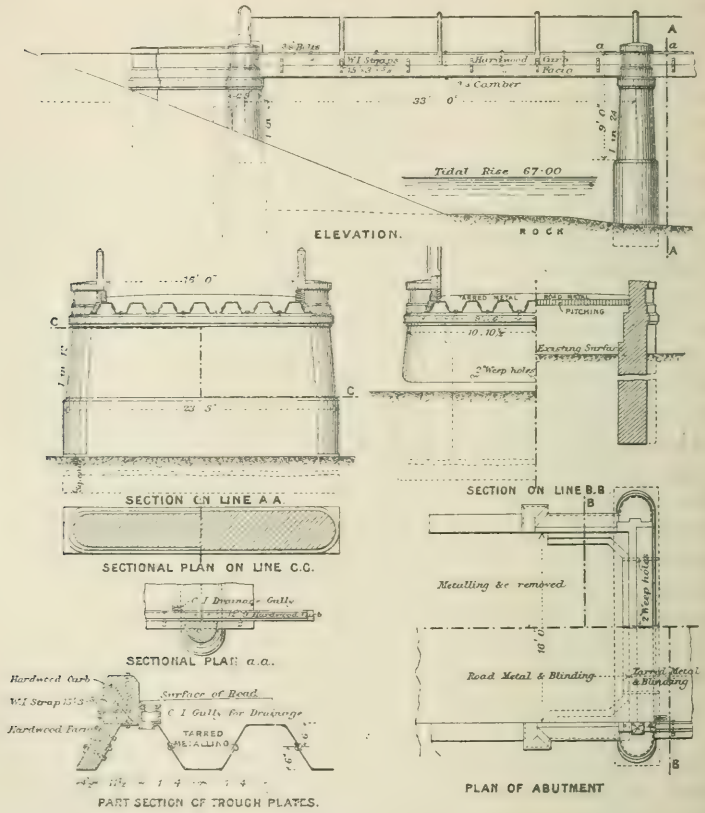
In Queensland and in other parts of Australia where heavy floods are frequent, low-level bridges are necessary for carrying the main stock-routes and roads for mail-coaches, carriers' teams, cattle and sheep over the rivers and creeks in the interior. High-level bridges, above the reach of all floods, would be too costly; and even if constructed would in many instances be unapproachable during the wet seasons, on account of the low-lying country on each side being submerged. Low-level bridges are found to be much less liable to be carried away by floods than semi-high-level structures; and are frequently built even where the higher bridge would, on account of being near to centres of population, be more desirable. Floating logs and driftwood cannot accumulate against a low-level bridge, for débris is not usually carried down-stream in considerable quantity until the bridge is entirely submerged, and then all trees, logs and rubbish can float harmlessly over it. A high-level bridge to be perfectly safe, must be above the level of the highest possible flood, and must admit of the free passage of logs underneath the superstructure. In some instances, during the floods of January, 1887, March, 1890, and February, 1893, high-level bridges have been destroyed, through no defect in the design or fault in construction, but solely on account of the water reaching such a height that the superstructure was subjected to great lateral pressure from the accumulated drift, to resist which they had not been designed. Bridges built at a low level must, however, be of strong and in some localities of exceptional construction, to successfully resist the repeated strains to which they are subjected every year during the flood-season.

The four bridges to be described are typical examples of low-level bridges which have recently been erected in Queensland.

Herbert River Bridge, Gairloch.

The level of the decking of this bridge, *Figs. 1*, is 10 feet above high water of ordinary spring-tide, or 29 feet below the highest flood-mark. The bridge has a total length over the abutments

Figs. 1.



Scale, $\frac{1}{16}$ inch to 1 foot.

Herbert River Bridge, Gairloch.

of 481 feet 3 inches; and consists of fourteen spans of 33 feet each, the clear width of roadway between the curbs being 16 feet.

Piers and Abutments.—The piers, thirteen in number, together with the abutments and wing-walls, are built of Portland-cement concrete composed of one part of cement, three parts of clean

sharp river-sand, and six parts of hardstone broken to 2-inch gauge. The string-courses under the steel superstructure were formed of a stronger concrete composed of one part of cement, two parts of sand, and three parts of hardstone broken to 1½-inch gauge. The pier foundations were laid on rock at depths varying between 4 feet 6 inches and 6 feet below high water, temporary wrought-iron caissons, constructed in sections bolted together, having been used. The maximum depth of sand overlying the rock-bottom was 4 feet 6 inches; and the maximum depth of sinking in the rock 1 foot 6 inches. Each pier has semicircular ends with a batter of 1 in 12 above the plinths; the batter of the sides, between the splayed plinth and the underside of string-course, being 1 in 24. All exposed faces of the concrete in the piers and abutments were floated with a mixture of one part of Portland cement to two parts of sand.

Superstructure.—The superstructure or decking of the bridge was formed of mild-steel trough-plates 12 inches in depth, weighing 25·82 lbs. per square foot of area covered. The plates were cambered to the extent of ¾ inch at the centre of each span, and the sections riveted together with ⅝-inch rivets at 6-inch pitch throughout. The trough form of superstructure possesses many advantages for short spans, as girders may be entirely dispensed with, and, in the case of low-level bridges, the small depth of the troughs offers but little resistance to the passage of flood-waters during the wet seasons. The whole of the steel-work received three coats of tar. For securing the steel superstructure to the piers and abutments, 1-inch lewis-bolts were fixed in the concrete string-courses, the upper surfaces of which were trowelled smooth and level, to form a uniform bearing for the steel-trough decking. The bolt-holes at one end of each trough were slotted to allow for expansion of the decking.

Roadway.—The road- or carriage-way was formed of metalling broken to 2-inch and 1-inch gauges in equal proportions, mixed with boiling coal-tar. The troughs were completely filled with tarred metal, and were covered to a depth of 7 inches at the crown and 5 inches at the curbs, being well punned and afterwards rolled and covered with sand. Drainage from the surface of the roadway is provided for by thirty gullies having outlets through holes cut in the trough decking. The curbs are of Moreton Bay ash, 12 inches by 9 inches, bolted to the steel decking; and the hand-railing is of hard-wood posts and iron chains easily removable.

Approaches.—The approaches were made in cutting through the sandy formation of the banks, the cutting for the south approach

having a maximum depth of 17 feet. The slopes were faced with bricks laid in cement; and concrete water-tables were constructed at the foot of the slopes.

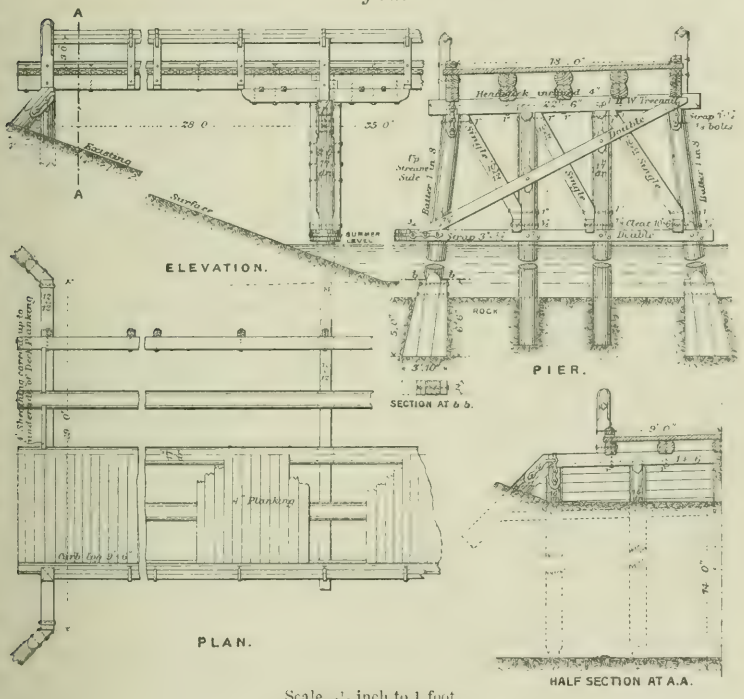
Flood Tests and Repairs.—During the construction of this bridge exceptionally bad weather was experienced; and two of the highest floods known in the locality occurred, resulting in considerable delays, loss of plant and materials, and damage to the approaches. In April, 1894, two and a half years after the bridge was opened for traffic, the Herbert river was visited by the most disastrous flood that has ever been recorded in the district, considerable damage occurring to the tarred metal or asphalt roadway on the bridge, necessitating its entire renewal. In repairing the roadway the quantity of tarred metalling, which, on account of its depth in the troughs of the decking, required a long time to set sufficiently hard for traffic, was reduced by filling the troughs to a depth of 12 inches, and forming a surface over the decking, with Portland-cement concrete, upon which tarred metalling or asphalt was laid to a depth of 6 inches, and reduced by rolling to 5 inches. The concrete was composed of one part of Portland-cement, one part of river sand, and six parts of stones from the river, of 2-inch, 1-inch, and $\frac{1}{4}$-inch gauges in equal quantities. The asphalt was formed of broken river-metal of 2-inch and 1-inch gauges in equal quantities, mixed with $\frac{1}{4}$-inch screened river-gravel, in the ratio of six parts of stone to one of screened gravel. After being thoroughly dried, heated, and well mixed with the required quantity of boiling coal-tar, it was stacked to allow the superfluous tar to drain off, and then laid on the surface of the concrete and rammed and rolled. The surface was finished with 1 inch of tarred sand and screenings, composed of four parts of coarse sand and two parts of fine gravel, screened, dried, heated and mixed with boiling coal-tar as before. After finishing, the entire surface was covered with clean sharp river-sand to a depth of $\frac{1}{2}$ inch; and, to give sufficient time for the asphalt to harden, a month was allowed to elapse before the bridge was re-opened for traffic.

Cost.—The contract for the construction of this bridge was let in January, 1890, and it was completed and opened for traffic on the 4th of November, 1891, the total cost of the bridge and approaches amounting to £7,737 16*s.* 7*d.* The cost of the bridge, exclusive of approaches, amounted to £5,704 4*s.* 0*d.*, or £11 17*s.* 0*d.* per lineal foot. The cost of the concrete and asphalt work, together with some other necessary repairs, amounted to £684; the total cost of the bridge being thus increased to £13 3*s.* 6*d.* per lineal foot.

Balonne River Bridge, St. George.

This bridge, *Figs.* 2, is wholly of bloodwood (*Eucalyptus corymbosa*), and consists of twelve spans of 35 feet each, with two end-spans of 28 feet each; the total length over the decking being 481 feet, and the width of roadway between the curbs, 18 feet. The height of the bridge above the lowest or dry-weather level of the river is 15 feet, the highest flood having reached a level of 16 feet

Figs. 2.



Scale, $\frac{1}{16}$ inch to 1 foot.

Balonne River Bridge.

above the bridge decking. The bed of the river consists entirely of hard rock.

Piers.—Each pier has four piles spaced at 6-foot 2-inch centres at the level of the headstock; the two outer piles having a batter of 1 in 8, and the two intermediate piles being planted vertically. The diameter of the piles, exclusive of sapwood, is 17 inches, the butt-end being placed downwards in every case. Each of the

outer or battered piles was lewised to the rock-bed of the river, each hole being cut to a depth of 5 feet, the dimensions at the bottom being 46 inches long by 14 inches wide. The sides and one end were cut vertically, and the opposite end tapered so as to reduce the length of the hole at the surface to 26 inches. The sides and ends of each hole were carefully rough-tooled to exact lines; and properly-shaped wedges of seasoned bloodwood were then inserted, and made to bear evenly against the rock. The feet of the piles were squared for a length of 6 feet 6 inches; they were then inserted in position between the wedges, and firmly driven home; the whole being securely bolted together above the surface of the rock. The wedges and the feet of the piles before being fixed were twice coated with Stockholm tar; and, after fixing, the interstices were completely filled in with strong-cement grout. The two intermediate piles in each pier, and also the abutment piles, were planted in rock, the holes for which, 24 inches in diameter, were jumped or excavated to a depth of 4 feet. The feet of the piles were freed from sapwood, and twice coated with Stockholm tar; they were then planted in the rock, the space round each pile being completely filled with cement concrete. The sites of eight of the twelve piers were above the summer level of the river, but the first four piers from the St. George side of the river were in water, necessitating the provision of a cofferdam for each pier, to admit of the holes in the rock being cut without the aid of divers. Each pier was capped with a 12-inch by 12-inch headstock inclined 4 inches in its length towards the upstream side of the bridge, and provided with double 10-inch by 6-inch walings above water- or rock-level, three 10-inch by 12-inch struts between the piles, and double 10-inch by 6-inch diagonal braces. The waling and braces were cogged on to the piles, and the whole well bolted together. The upstream ends of each pair of walings were shaped and blocked solid to form a cutwater, and were well secured with wrought-iron straps and bolts.

Superstructure.—Each span consists of five girders or stringers scarf-jointed over the piers, and carried upon single corbels, 14 feet long, through which the girders were bolted. The corbels were cogged on to the pier headstocks; and, in addition to being bolted, the girders were keyed to the corbels with well-seasoned wedge-keys tightly driven, working 3 inches square, and having a 4-inch projection on each side for tightening. The superstructure is secured to the piers by through-bolts and anchor-bolts. The decking consists of 9-inch by 4-inch planks laid

transversely over the girders in one length from side to side, and spiked down with 8-inch by ½-inch spikes. The outer girders and corbels exposed to view are of hewn timber 14 inches by 12 inches; the inner girders and corbels being of round timber 17 inches in diameter, exclusive of sapwood, adzed flat to a thickness of 14 inches over all bearings and for the planks of the decking. The entire superstructure is built with an inclination of 4 inches towards the upstream side to prevent lodgment of driftwood under the bridge decking in time of flood. The abutments were sheathed at the back of the piles with 4-inch planking, carried also along the wings of the abutments. The curbs measure 9 inches by 6 inches, and are rounded on one edge and bolted through the decking and girders; the curb on the upstream or lower side of the bridge being raised 1½ inch to allow for drainage from the surface of the decking. The handrails, 6 inches square, are placed diagonally on 9-inch by 6-inch intermediate posts, and 9-inch by 9-inch main posts over the piers, terminating at the ends of the bridge in 12-inch by 12-inch guard-posts securely fixed to the girders of the end spans and tenoned into the abutment headstocks. The handrailing is only 3 feet above the decking, and of exceptional strength, without intermediate rails and wires, so as to offer as little resistance as possible during floods, and to enable it to withstand the pressure due to the accumulation of flood débris. Strong permanent handrails are to be preferred to movable handrails, which are troublesome and expensive, and their removal at the vital moment is often neglected.

Painting and Tarring.—The whole of the timber-work received three coats of oxide paint, with the exception of the decking, which was covered with three coats of Stockholm tar.

Flood Tests.—Since it was opened for traffic, this bridge has been several times submerged by floods without sustaining injury.

Cost.—The construction of the bridge was commenced in October, 1890, and it was opened for traffic in June, 1892, after many troublesome delays in consequence of wet weather and floods. The total cost amounted to £4,467 16*s.* 4*d.*, inclusive of approaches, which alone cost £419 10*s.* 0*d.*, the cost of the bridge per lineal foot amounting to £8 8*s.* 4*d.*

Mary River Bridge, Tiaro.

This bridge was built to replace that washed away by floods in July, 1889. Its total length is 306 feet, and it consists of seven 35-foot spans and two 28-foot end-spans; the entire work, with the

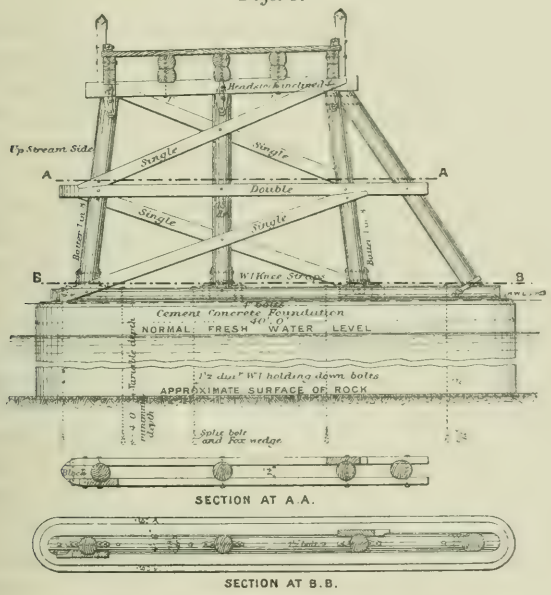
exception of the pier foundations, having been constructed of Queensland grey ironbark.

Foundations.—The concrete work in the foundations for the piers was built within timber framing sheeted down to the rock-level. The bottom was sealed with a layer of concrete, after which the water was pumped out and the concreting completed in layers 12 inches thick well rammed. The concrete was composed of six parts of broken stone, of 2-inch gauge, three parts of river-sand and one part of Portland-cement. Each foundation is 40 feet in length and 4 feet 6 inches in breadth, and is built to a level of 3 inches above high water.

Piers.—Each pier consists of three piles 18 inches in diameter, free from sapwood, spaced 9 feet 3 inches from centre to centre at the headstock level, and placed with the butt end downwards. The centre pile is vertical and the two outer piles have a batter of 1 in 8. A strut, 18 inches in diameter, is provided on the downstream side of each pier with a batter of 1 in $1\frac{1}{2}$ to further increase the base and to assist in resisting the overturning tendency during floods. The piles and struts are tenoned into the headstocks and sills, and secured to the latter by wrought-iron knee-straps and bolts. The sills are 37 feet 6 inches long and 18 inches in diameter, squared on the top and bottom to a depth of 12 inches, and bedded in cement. They are secured by five wrought-iron anchor or holding-down bolts passing through the concrete foundations, and to a depth of 4 feet into the solid rock, where each bolt is fox-wedged. Holes for the bolts were drilled in the rock to the required depth, through 4-inch tubes driven through the sand where it overlay the rock. Wrought-iron bolts $1\frac{1}{2}$ inch in diameter, with the lower end of each split for a length of 12 inches, and having wrought-iron fox-wedges inserted, were then put in place and firmly driven so as to fill each hole tightly at the bottom. The tubes were left in position and afterwards completely filled with strong cement grout. The bolts were increased to 2 inches in diameter at the screwed end, and over the sills they were provided with strong cast-iron washers and double nuts. The bolts vary in length between 9 feet 6 inches and 13 feet; and they are spaced at intervals of 5 feet, 6 feet, 11 feet and 10 feet respectively in each pier foundation, three being on the upstream side of the central pile, and two on the downstream side, *Fig. 3*, the greater lifting or overturning force being exerted at the upstream end of each pier when the floods reach the level of the underside of the superstructure. After the bridge has become completely submerged, its liability to injury

from flood-pressure or floating logs and débris ceases, until the water during subsidence reaches the level of the decking, when this element of danger to the structure again manifests itself. Each head-stock to the piers is of 14-inch by 14-inch squared timber and 22 feet 6 inches in length, inclined 4 inches from the downstream to the upstream pile to give the required inclination to the superstructure. Each pier is well braced and stiffened with 12-inch by 6-inch walings and braces cogged and bolted to the piles, the upstream end of each pair of walings being filled solid

Figs. 3.



Scale, $\frac{1}{16}$ inch to 1 foot.

Pier of Mary River Bridge, Tiaro.

and rounded to form a cut-water and prevent floating driftwood being caught between the walings.

Superstructure.—The decking of the bridge is at a level of 21 feet above high water, and 31 feet below the level of the highest known flood; the width of the roadway between the curbs is 18 feet. The design of the superstructure and abutments is similar to that of the Balonne river bridge at St. George, *Figs. 2*, the decking and girders being inclined or canted over in an upstream direction to the extent of 4 inches.

Flood Tests.—This bridge has been severely tested since its erection, several floods having passed over it, that of February,

1893, being the highest and most disastrous on record in the valley of the Mary, but no injury was sustained by the structure.

Cost.—The contract for the bridge was signed on the 9th September, 1890, and, with approaches, completed and opened for traffic on the 23rd of February, 1891; the total cost, exclusive of supervision, amounted to £2,913 3*s.* 2*d.*, the cost of the bridge, exclusive of approaches, being £9 5*s.* 2*d.* per lineal foot.

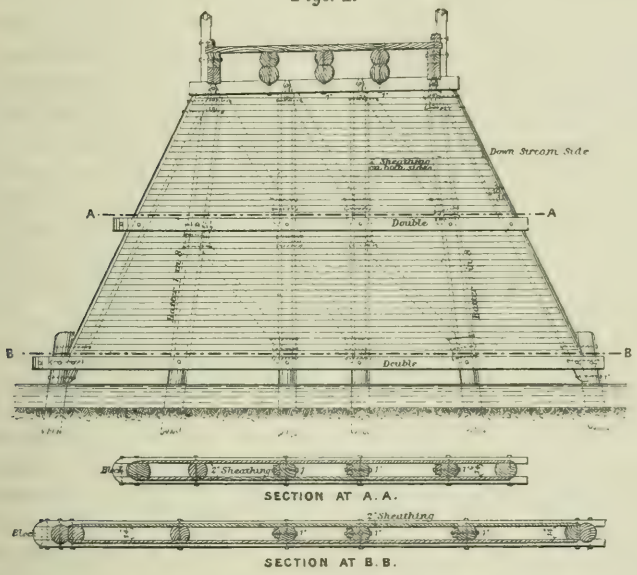
Mary River Bridge, Gympie.

The old Channon Street bridge over the Mary River at Gympie was destroyed by heavy floods in July, 1892. Plans were prepared towards the end of that year for a timber bridge to be erected on the original site and at the same height as the old structure, 28½ feet above the summer-level of the river, or about 45 feet below the highest known flood-level. Tenders were invited for the work in January, 1893, and a contract let early in March. There are seven spans, one 40 feet, two 38 feet, two 30 feet, and two 20 feet long; the total length of the decking is 221 feet, and the width of roadway between the curbs 18 feet. The bridge is built of ironbark, blue gum, and spotted gum; and in design the superstructure is similar—excepting as to length of spans—to the St. George and Tiaro Bridges.

Piers.—The piers are of a design not previously adopted in low-level timber bridges, the piles being close sheathed on both sides of the pier with planking, *Figs. 4*, to prevent floating logs, branches of trees, and other débris becoming locked or entangled in the bracings during floods, and thereby endangering the safety of the bridge. This new feature in timber bridge-piers has since been adopted in several other bridges, and has given satisfactory results. Each pier of the Gympie bridge consists of four main or bearing piles and two strut piles, 18 inches in diameter at the head and 12 inches in diameter at the toe, and driven to a hard foundation. The outer main piles have a batter of 1 in 8, the two intermediate piles being vertical; whilst the two struts, from the headstock to the strut piles, have a batter of 1 in 2, the pier-base being 46 feet. The piles were driven to an average depth of 21 feet, with a 25-cwt. monkey falling 8 feet, each pile being shod with a wrought-iron shoe weighing 28 lbs. The headstocks of the piers are 12 inches square and 22 feet 6 inches long, and are inclined 4 inches in their length in an upstream direction. The walings are double 12-inch by 6-inch timbers, and are cogged and bolted to the piles, the usual diagonal bracings being omitted; but diagonal struts 12 inches by 10 inches between the piles are substituted, each

strut being bolted at each end to the piles, and abut upon chocks or cleats checked on to the walings and bolted to the piles. All the piles are squared or adzed to a thickness of 12 inches above the level of the bottom walings to receive the plank sheathing. The sheathing consists of 6-inch by 2-inch hard-wood planking, laid parallel to the walings in long lengths flush and close, and secured to the piles and squared struts with three $\frac{3}{8}$-inch spikes 5 inches long. The whole of the timberwork in the piers of this bridge was coated three times with Stockholm tar, and the superstructure

Figs. 4.



Scale, $\frac{1}{16}$ inch to 1 foot.

PIER OF MARY RIVER BRIDGE, GYMPIE.

received three coats of red-oxide paint. These are found to be the best preservatives for timber in the climate of Queensland.

Cost.—The bridge was opened for traffic on the 11th October, 1893, the total cost, inclusive of approaches, amounting to £1,500 8*s.* 6*d.*, the cost of the bridge alone being £1,443 3*s.* 6*d.*, or equal to £6 11*s.* 6*d.* per lineal foot.

The bridges described in the Paper were designed by the Author, who also supervised their construction.

The Paper is accompanied by four sheets of drawings, from which the *Figs.* in the text have been prepared.

[APPENDIX.

APPENDIX.

COST OF THE MATERIALS USED IN THE CONSTRUCTION OF THE FOUR BRIDGES DESCRIBED IN THE PAPER.

Herbert River Bridge.

	£	s.	d.	
Excavation for foundations of piers and abutments	1	5	0	per cubic yard.
Portland cement concrete (6, 3 and 1)	3	5	0	„ „ „
Steel-trough superstructure	24	0	0	„ ton.
Wrought-iron in bolts, &c.			4	„ lb.
Sawn or squared timber		4	0	„ cubic foot.
Tarred metalling on decking		11	0	„ „ yard.

Balonne River Bridge.

Bloodwood piles, 17 inches diameter		3	6	„ lineal foot.
Round timber in girders and corbels 17 inches diameter		4	9	„ „ „
Sawn or squared timber		4	9	„ cubic „
Wrought timber in handrails, &c.		6	6	„ „ „
Wrought-iron in bolts, &c.			7	„ lb.

Mary River Bridge, Tiaro.

Ironbark piles, 18 inches diameter		4	3	„ lineal foot.
„ „ 17 „ „		4	0	„ „ „
Sawn or squared timber		4	0	„ cubic „
Round timber in girders and corbels, 17 inches diameter		4	3	„ lineal „
Wrought timber in handrails, &c.		7	0	„ cubic „
Wrought-iron in bolts, &c.			4	„ lb.
Excavation to rock for pier foundations		10	0	„ cubic yard.
Sinking holes in rock for lewis-bolts	1	0	0	each.
Portland cement concrete in foundation	2	10	0	per cubic yard.

Mary River Bridge, Gympie.

Ironbark piles 16, 17 and 18 inches diameter		3	1	„ lineal foot.
Round timber in girders and corbels, 16, 17, and 18 inches diameter		3	0	„ „ „
Sawn or squared timber		2	10	„ cubic „
Wrought timber in handrails, &c.		3	2	„ „ „
Wrought-iron in bolts, &c.			5	„ lb.

(Paper No. 2903.)

(Abridged.)

"The Construction, Equipment and Working of Light Railways."

By Robert Jarratt Money, Assoc. M. Inst. C.E.

In the construction of light railways, economy is effected by the reduction of the gauge and of the maximum speed allowed on main lines. With a reduced speed a lighter and therefore cheaper rolling-stock may be adopted, and consequently a lighter permanent way and less solid road-bed. To effect economy, it is, however, not always necessary to reduce the gauge. In a flat country a line of standard gauge may be economically constructed, and it is chiefly in rough mountainous country that, by the use of sharper curves and steeper gradients, thereby avoiding deep cuttings and high banks, a narrow gauge effects considerable saving in the cost of construction. But while in this case the cost of construction is reduced, the sharp curves and steep gradients increase the working expenses, and therefore the cost of working must be considered at the same time as the cost of construction.

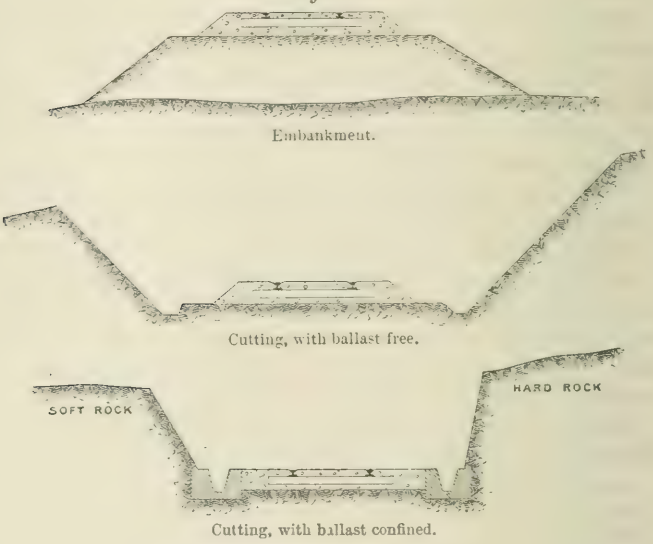
Light railways may be divided into four classes:—1. feeders to main lines, in the construction and working of which certain economies may be admitted; 2. subsidiary lines, upon which there is little or no interchange of traffic with the main lines, and to which economies of construction and working may be applied on a larger scale; 3. subsidiary lines, the chief traffic upon which is in goods, and where a lower speed may be adopted; and 4. narrow-gauge lines. The first three classes include railways which, without forming an integral part of the main-line systems, are sufficiently large feeders to them to render a break of gauge inadvisable, and those lines passing through cultivated land of small value where a narrow gauge would effect little economy. These lines should be of the standard gauge but with sharper curves and steeper gradients than on the main lines, where such economy will not weigh too heavily on the working. They must be so constructed as to admit the main-line rolling-stock, except locomotives with long rigid wheel-base, but at a reduced speed. The essential difference

between the three classes is their maximum speed, which in Italy is 25 miles, 18½ miles and 12½ miles per hour respectively.

Class 1.—Upon Italian railways of the first class the curves may not be of smaller radius than 650 feet, and the gradients may not exceed 1 in 28½. The width at formation-level, 16 feet 6 inches, is somewhat less than the main-line standard. *Figs. 1* show sections of the permanent way of such lines on bank and in cutting.

Class 2.—To this class belong railways worked at a reduced speed with special lighter rolling-stock, but constructed to admit of the passage of main-line carriages and goods wagons. The permanent

Figs. 1.



STANDARD-GAUGE LIGHT RAILWAY.

Scale, 1 inch = 12 feet.

way may consequently be lighter and the road-bed narrower. The minimum radius of curves may be between 500 feet and 330 feet, and the maximum gradient 1 in 20. The construction is similar to that shown in *Figs. 1*, but the width at formation level is reduced to 14 feet 6 inches, and the other dimensions in proportion. Flange-rails are used weighing between 50 lbs. and 60 lbs. per yard.

Class 3.—This class comprises lines worked with special rolling-stock, but constructed to allow of the passage of main-line goods wagons. The economies of construction may be still greater than in the second class, the speed being considerably lower. The mini-

mum radius of curves is 330 feet, and the maximum gradient 1 in 20. The construction is also similar to that shown in *Figs. 1*, but the width at formation-level is 13 feet, and the other dimensions in proportion. The flange-rails weigh between 40 lbs. and 50 lbs. per yard.

Class 4.—Narrow-gauge lines may be adopted when the amount of traffic is small and where exceptional difficulties of construction are met with. The reduction from standard gauge must not be too small, because while cutting off all the advantages of a similar gauge, it does not effect much economy. Examples of such lines are to be found in Belgium, Switzerland, Sweden and elsewhere.[1] On the other hand it must not be too great, as, except in special cases, a gauge of say 2 feet, while affording considerable reduction in the cost of construction, increases the working expenses. On such a line, with the great overhang of the locomotives, a small amount of oscillation deranges the permanent way, increasing considerably the cost of maintenance, while the too small capacity of the vehicles presents difficulties in the transport of passengers and not a few classes of goods.

The narrow gauges in most general use are 3 feet 6 inches, 1 metre, and 2 feet 6 inches, of which the mileage at present in operation, together with other particulars of three railways, is shown in Appendix I. While in Italy two gauges, of 3 feet $1\frac{7}{16}$ inch and 2 feet $3\frac{9}{16}$ inches respectively, have been fixed for narrow-gauge railways, as yet none have been built to the smaller gauge. According, therefore, to general practice narrow gauge lies between 3 feet 6 inches and 2 feet 6 inches.

The dimensions and speeds adopted on the Palermo-Corleone Railway, in Sicily, are:—

Gauge, 1 metre centre to centre of rails,	3 feet $1\frac{7}{16}$ inch.
Minimum radius of curves	230 „
Maximum gradient	1 in 25·64.
Width at formation-level	11 feet 6 inches.
Permanent way, steel flange rail . .	40 lbs. per yard.
Sleepers (red oak)	5 feet 6 inches by 7 inches by $4\frac{1}{2}$ inches.
Minimum depth of ballast under sleepers	4 inches.
Maximum speed on tangent	$15\frac{1}{2}$ miles per hour.
„ „ „ curve	$12\frac{1}{2}$ „ „ „

	Hours.	Mins.		Miles per Hour.
Running time for the whole 42 miles, including stops	3	50	=	$9\frac{1}{3}$
„ „ „ excluding stops.	3	27	=	11

[1] See also "Light Railways for the Transport of Sugar-cane in Australasia," by C. E. Forster, B.A., Assoc. M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. cxxii. p. 202.

One of the objections to a break of gauge is the cost of transshipment, but this affects goods only. Goods in baggage and mixed vans are, even in ordinary service, unloaded and reloaded at all junctions with the main line, and sometimes even on the way in order to load the vehicles better. To these goods then, the inconvenience of transshipping on the narrow gauge does not apply. It exists, however, in the case of complete wagon-loads. On the Broelthal Railway in Germany, the cost of transshipping goods is 3*d.* per ton. In Northern Italy the handling of the goods at the stations is in some cases entrusted to contractors for the sum of 5*d.* per ton transshipped. On other Italian lines it costs sometimes more and sometimes less, so that for Italy 5*d.* per ton may be considered a fair average price, the work being heavy, and the staff continuously employed. If this expense for transshipment of 5*d.* per ton is compared with the mean cost of carriage, which is 1*s.* 1·10*d.* per ton-mile, or with the lower charges of 0·80*d.* and 0·64*d.* per ton-mile which full wagon-loads pay, it follows that transshipment is equal to a carriage of 6 miles, and therefore the

Fig. 2.

Railway of Standard Gauge on Highway.

Scale, 1 inch = 12 feet.

distance of carriage and the amount of traffic in full wagon-loads give data to be used in considering the question of narrow gauge.

Lines laid on Highways.—Light railways may be laid at the side of highways when these are suitable. In such cases a minimum width of 16 feet 6 inches should be left, and a barrier erected between the rails and the highway, *Fig. 2.* When, however, the length is short and the speed low, this barrier may be omitted. There are many such examples in Italy under the name of steam-tramways, one of the best being the line from Rome to Tivoli.[1] On the Palermo-Corleone Railway, the first 4 miles from Palermo run alongside and on a level with the highway, separated only by a low stone wall 9 inches to 15 inches high, serving more to mark the boundary of the railway company's property and to maintain the ballast, than as a protection to the road traffic.

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 344.

Although there is considerable traffic on the highway, both in carts and foot passengers, no difficulty is experienced in working the railway on these 4 miles. The lines in Italy may be laid on the highways, if the rails do not project above the surface, without any barrier, provided that ordinary vehicles can travel without inconvenience, that the line is worked with light rolling-stock, by tramway engines, and at a speed not exceeding 10 miles per hour. Economical railways may cross other railways—even main lines—on the level, provided both lines are protected by safety appliances; and they may join existing lines when necessary between stations, provided the junction is supplied with signals and the necessary automatic safety appliances.

For lines of different gauges a third rail may be laid between those of standard gauge to give access to a station, and a third rail may be so used where the main-line road-bed can also serve for a narrow-gauge line. Continuous fencing is required only at dangerous places, such as the close proximity of a road or pasture fields. Level-crossing watchmen, distant signals, and the electric telegraph may be dispensed with when trains do not run at high speed or at night. Station buildings for both standard and narrow-gauge lines should be as simple as possible, adapted to the special requirements of the place and to the importance of each station. In all intermediate stations of little importance a single room for use as an office will suffice, the tickets in such cases being sold by the train-conductor. Goods sheds should be attached to the station-building with a communication between them. Platforms may be dispensed with or considerably modified on all lines, except those where carriages of the main-line type are used. Except in special cases, level crossings may be left unguarded, a warning notice to the public being sufficient. Where the line crosses roads of much traffic, or where the nature of the country precludes an uninterrupted view of the line, some simple form of barrier should be erected. Distant signals may be dispensed with, and home signals provided only at those stations where trains cross. Metal bed-plates should be inserted between the rails and sleepers to increase the life of the latter and to maintain the correct gauge on sharp curves. On the Palermo-Corleone Railway they were at first laid only on joint sleepers and on some of the sleepers in the sharpest curves; this number being found insufficient, it was increased. At first the bed-plates were pierced for three spikes; but this was afterwards reduced to two, as so many spike-holes were found to be injurious to the sleepers.

Gradients.—To determine the gradients on a light railway, the

nature of the traffic, details of the proposed working, and the profile of the line, must be known. The amount of traffic has no effect upon the extra expenses of lowering gradients, while the increased cost of working from adopting the maximum gradient is proportional to the traffic. On lines with small traffic it is advisable to adopt the maximum gradient, when thereby a considerable saving in cost of construction may be effected, while on lines with the prospect of a good traffic, it is well to make some sacrifice in first cost of construction, avoiding as much as possible the maximum gradient, so that when the traffic is fully developed, it may be worked economically. On the Porto Empedocle-Termini Railway, in Sicily, with gradients of 1 in 33·33, the consumption of coal, for the same amount of traffic, is double that on Italian railways with medium gradients, and other locomotive charges follow the same rule. On railways in the province of Calabria, with a traffic of £5 per mile per week, or £257 per mile per annum, the additional working-expenses from economical construction were £1 5*s.* per mile per week (£65 per mile per annum), or one-fourth.

In his work on "Les Pentes Économiques," Mr. de Freycinet states that, "In very rough country, with special locomotives and by doubling up trains, if the traffic is less than on the six great French railways, the most economical gradient will be 1 in 25, and even more on lines of small importance. When the rough portions are smaller, but repeated over the whole line, if the length of line on gradient equals that on the level, the most economical gradient for lines of moderate traffic will be 1 in 55, and therefore more if the length on gradient is greater."

The limiting gradients on Italian railways are :—On lines worked with main-line rolling-stock $3\frac{1}{2}$ per cent., and on other lines 5 per cent. In tunnels the maximum gradient should be reduced because of the lower adhesion.

Curves.—On lines of the first class, the limiting radius of curves for Italian railways is 650 feet on ordinary gradients, and 800 feet on steep gradients. On the South-Western of Venezuela Railway, a 2-foot gauge railway, the limiting radius is 150 feet on 3 per cent. gradients, and 200 feet on $3\frac{1}{2}$ per cent. gradients. On the La Guaira and Caracas Railway in Venezuela, of 3-foot gauge, there are curves of 140 feet radius on gradients of $3\frac{1}{2}$ per cent. This should be considered an extreme case. In Italian practice the minimum radius of curvature is 650 feet, 500 feet to 330 feet, and 330 feet on railways of the first, second, and third classes respectively. For a gauge of 3 feet $1\frac{7}{16}$ inch it is 230 feet, and of 2 feet $3\frac{9}{16}$ inches 130 feet. Where bogie trucks are adopted for the

rolling-stock, these limits may be further reduced. Curves of similar direction should be joined by a compound curve and not by a tangent; this has considerable effect on the smoothness of running of a train on a mountain line, where the curves are numerous and of small radius. When curves occur on maximum gradients, they should be compensated for by reducing the gradient so as to offer no greater resistance than the adjoining tangents. This amount of compensation varies in practice between 0·03 foot and 0·05 foot per 100 feet per degree of curve (1° = 5,730 feet radius) for standard gauge. On the Rocky Mountain section of the Canadian Pacific Railway, with minimum curves of 10° (573 feet radius) on a maximum gradient of 4·5, per cent., the equation used was 0·03 foot per degree of curve;[1] while on the Rocky Mountain section of the Great Northern Railway, U.S.A., with the same minimum curves of 10° the equation used was 0·04 foot per degree of curve. On the Palermo-Corleone Railway, the minimum distance between reverse curves is 50 feet, the length of the longest train ascending gradients being 142 feet. This, therefore, allows, on each portion of reverse curves in ascending trains, 46 feet. No trouble was experienced with these reverse curves, the trains running safely at all speeds. On the South-Western of Venezuela Railway of 2-foot gauge, the minimum distance between reverse curves is 21 feet. The length of the longest train ascending gradients is 140 feet, which therefore allows on each portion of reverse curves 59 feet. The setting out of this line would have been easier had a shorter tangent between reverse curves been admitted; but further experience on this point is necessary to state whether a shorter tangent would have been admissible.

Rolling-stock.—While the tractive power required on curves for bogie trucks shows a decided reduction over that required for stock with a rigid wheel-base, considerable improvement is to be made in the ratio of dead-weight to load. The Author is of opinion that the cost of traction may be substantially reduced by the use of roller bearings and a satisfactory form of flexible wheel-base, combined with independent wheel rotation.

The permanent way being lighter and the curves sharper than on the main lines, special types of locomotives are necessary with a shorter rigid wheel-base, using all their weight for adhesion,

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[1] See "On the Construction of the Canadian Pacific Railway (Rocky Mountain Division) during the Season of 1884," by G. C. Cuningham, M. Inst. C.E., Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 105.

and with less weight on each axle. The following dimensions have been adopted in Italian practice.[1]

Six Wheels Coupled.	Class 2.	Class 3.	Class 4.	
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Diameter of driving-wheels	3 3	2 7	3 3	2 7
Rigid wheel-base	8 6	6 6	6 0	5 0
Maximum weight per axle . . tons	10	8	6	5

Railways of the first class have carriages of the same type as the main lines. Those in the second and third classes should be of the American or Swiss type, with a longitudinal passage along the centre, and end platforms with communication between. When bogie underframes are not adopted, the rigid wheel-base on Italian railways does not exceed 9 feet 10 inches and 8 feet 3 inches, and the weight is such as to allow six passengers and a little more than six per tare ton in the second and third classes respectively. For narrow-gauge lines the weight of the carriages per axle must be greater than that of the locomotives; the former should have a central coupling and buffer, as each line may require different types and dimensions. On economical railways of whatever gauge, excluding those of the first class, it is most desirable there should be only two classes for passengers, for the economical working of the line.

In Italy, when bogie underframes are not adopted, the wheel-base does not exceed 8 feet 3 inches and 7 feet 4½ inches in the second and third classes respectively. The weight of the wagon in each case must not exceed half the load. For covered or box-wagons one type only is recommended, while for open wagons there should be as few types as possible. On the Palermo-Corleone Railway four-wheeled wagons, having a rigid wheel-base of 5 feet 11 inches, caused great trouble owing to frequent derailments. Trains composed of this stock required good driving and very careful braking. Upon additional wagons being required, Mr. W. Shelford, the Company's consulting engineer, adopted bogie trucks and wagons with a rigid wheel-base of 4 feet and bogies 18 feet centre to centre, which gave complete satisfaction. The tractive-power required on curves to haul two bogie-wagons was equal to that required for three four-wheeled wagons.

[1] See also Minutes of Proceedings Inst. C.E., vol. cxx. pp. 35–42, and Appendix I, *post*.

The weights of the rolling-stock on the Palermo-Corleone Railway are :—

	Empty.	Full.
	Tons.	Tons.
Carriages :—		
1st class, 16 seats (longitudinal)	3	5
2nd „ „ „	3	5
3rd „ 32 seats (transverse)	3	7
Baggage vans	3	5
Wagons :—		
Four-wheeled (complete wagon-load)	3	9
„ (loaded with general goods)	3	6
Bogies, eight-wheeled (complete wagon-load)	6	18
„ „ (loaded with general goods)	6	9

The following Table shows the engine-loads used in making up trains :—

Railway.	Length of Continuous Inclines.	Maximum Ascending Gradient.	Summer.		Winter.	
			Two Axles Coupled.	Three Axles Coupled.	Two Axles Coupled.	Three Axles Coupled.
	Miles.	Per Cent.	Tons.	Tons.	Tons.	Tons.
Palermo–Ficuzza	2¼ and 3	3·9	47	50	42	45
Ficuzza–Donna Beatrice	..	..	100	105	95	100
Donna Beatrice–Corleone	3	3·9	47	50	42	45

Working.—The expenses upon coal, repairs to locomotives, and renewal of rails form about one-fourth the total working-expenses on Italian railways. They may be considered proportional to the velocity of the traffic travelling over the line. In Italy the speed of omnibus, passenger and mixed trains, varies between 15 miles and 18½ miles per hour, including stops, and between 9 miles and 12½ miles per hour for goods trains. A reduction of the speed by one-third would reduce the total working expenses by about 8 per cent. The number of trains should be reduced to meet only immediate needs ; for stations a hut must suffice, tickets must be sold by conductors, and on short lines the trains should be worked by one locomotive, thereby rendering the telegraph unnecessary. The trains must be suited to the requirements of the district, but in view of the fact that a night service increases the cost of running a train. Excluding this, and reducing the speed, the patrolling of the road will be easier and less costly,

since it will be sufficient to examine it once a day, and only necessary to signal obstructions.

On the Palermo-Corleone Railway there are nine women employed at the level crossings, at a monthly salary ranging between 5*s.* and 9*s.* They perform their work admirably, not only protecting the level crossings, but also signalling the trains.

The station expenses per mile on Italian railways are:—

	£
Main lines	296 per mile.
„ (Sicily)	125 „
Light railways	74 „
Narrow gauge	40 „
Palermo-Corleone (metre gauge) . .	36 „

The train service may be much simplified, if the line is short, by making the trains cross at fixed points, and by the use of the train staff, which dispenses with the use of the telegraph, or at least very considerably reduces it. Experience on the Continent has shown that the administration should be decentralized and local, and that whenever possible the working of economical railways should be separated from that of the main line. In Appendix II are given particulars relating to the Sicilian and Palermo-Corleone Railways, and in Appendix III an account of the working of the Bavarian economical railways.

To construct and work economically new lines of railway, before reducing the gauge the speed should be reduced, and consequently the diameter of the locomotive driving-wheels, as well as the rigid wheel-base. Economy will therefore be effected in the construction, because the ordinary roads may be utilized, and in every case sharper curves, steeper gradients, and lighter bridges may be adopted. For the rolling-stock and permanent way also, a lighter type, yet always well suited to its work, may be adopted; and in working economy will result, because the useful load of a train compared with its dead load will be greater, the wear of the permanent way, locomotives and rolling-stock less, the consumption of fuel and supplies will be smaller, as also the repairs to rolling-stock, and the staff required along the line and in the stations will be diminished. When all these sources of economy do not suffice to render a railway financially successful, then, and not till then, should the question of reducing the gauge be considered.

The Paper is accompanied by three sheets of tracings, from a selection of which the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

NARROW-GAUGE RAILWAYS AT PRESENT IN OPERATION.[1]

	2 feet 5¼ inches and 2 feet 6 inches.	3 feet, 0·95 metre and 1 metre.	3 feet 6 inches.
	Miles.	Miles.	Miles.
Africa, S.	..	..	2,570
America, U.S.	..	5,291	91
Argentina	..	2,597	
Australia	..	..	4,766
Bolivia	574		
Bosnia	261		
Brazil	406	5,139	336
Canada	..	..	212
France	..	1,880	
„ (African Colonies)	..	..	479
Germany	302	482	
India	188	7,637	
Italy	..	463	
Mexico (approximate)	..	1,976	
New Zealand	..	..	2,036
Newfoundland	..	..	346
	1,731	25,465	10,836

[1] For reference to further information on the subject, see "A Catalogue of Books, Reports, Papers, and Articles relating to Light Railways," compiled by Corrie L. Thompson. London, 1895.

TABLE OF PARTICULARS RELATING TO THREE NARROW-GAUGE RAILWAYS.

	Palermo-Corleone Railway.	South Western Venezuela Railway.	South Western Venezuela Railway.	Quebrada Railway, Venezuela.	Quebrada Railway, Venezuela.
System	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
Gauge	Metre	2-feet	2-feet	2-feet	2-feet
Sharpest curve feet	230—328	150—200	150—200	150—200	150—200
Steepest gradient	1 in 25	1 in 28½	1 in 28½	1 in 19	1 in 19
Length of incline	Various	Various	Various	1 mile	1 mile
Type of locomotive	Tank	Tank	Tank	Tank	Fairlie
Diameter of cylinders inches	12½	13	10½	12	9
Stroke „	18	18	18	18	14
Axles	3 coupled 1 pony	3 coupled 1 pony	2 coupled 2 bogie	3 coupled 2 bogie	6 in 2 sets 3 coupled
Rigid wheel-base	6 feet	5 feet 10 inches	5 feet 10 inches	9 feet 10 inches	6 feet
Diameter of wheels	2 feet 10½ inches 2 feet	2 feet 6 inches 2 feet	3 feet 2 feet	2 feet 6½ inches 1 foot 6 inches	.. 2 feet 6 inches
Heating-surface square feet	495	489	363	421	785
Weight of loaded locomotive	24 tons 6 cwt.	23 tons	17 tons 10 cwt.	22 tons 5 cwt.	29 tons 10 cwt.
Greatest weight on an axle	6 tons 4 cwt.	6 tons 10 cwt.	6 tons 5 cwt.	5 tons 16 cwt.	4 tons 18 cwt.
Gross load hauled up incline	50 tons	64 tons	30 tons	63 tons	61 tons
Builders of locomotives	Hawthorn, Leslie & Co.	Kitson & Co.	Falcon Engine Co.	Dübs & Co.	Hawthorn, Leslie & Co.

APPENDIX II.

SICILIAN RAILWAYS—MAIN LINES, STANDARD GAUGE.

	Kilometres.
Length of line on level	118 or 20 per cent.
„ „ gradient of 1 in 200 or less	123 „ 20 „ „
„ „ „ „ 1 in 66	235 „ 39 „ „
„ „ „ „ over 1 in 66	129 „ 21 „ „
Total	605
Length of straight line	303 or 50 per cent.
On curves over 500 metres (1,640 feet)	122 „ 20 „ „
„ „ of 500 metres radius or less	160 „ 30 „ „
Maximum gradient	1 in 31·5
Minimum radius of curves	492 feet.

ALLOWANCE FOR LOCOMOTIVES.

Coal—	Kilogram.	
For each axle-kilometre	0·27	reduced to 0·26 kilog. during months May–October.

NOTE.—Locomotives hauling express trains receive 30 kilograms extra. Each hour standing in steam is equivalent to 2 locomotive kilometres, and each hour shunting trains to 5 train kilometres.

Oil—	
Four-coupled locomotive	0·028 per kilometre.
Six- ,, ,,	0·030 ,, ,,
Eight- ,, ,, (special mountain locomotive)	0·035 ,, ,,

NOTE.—Express trains with four- and six-coupled locomotives receive 0·010 kilogram and 0·015 kilogram extra respectively.

Shunting trains at stations, four-coupled locomotives	0·075 per hour.
,, ,, ,, other locomotives	0·100 ,,

PALERMO-CORLEONE RAILWAY—METRE GAUGE.

	Kilometres.	
Length of line on level	7·7	or 12 per cent.
,, ,, gradient of 1 in 200 or less	9·4 ,, 14	,, ,,
,, ,, ,, 1 in 66	9·5 ,, 14	,, ,,
,, ,, ,, ,, over 1 in 66	40·8 ,, 60	,, ,,
Total	67·4	
Length of straight line	37·2 ,, 55	,, ,,
Curved line over 500 metres radius (1,640 feet)	2·0 ,, 3	,, ,,
,, ,, 500 metres radius or less	28·0 ,, 42	,, ,,
Maximum gradient	1 in 25·6	
Minimum radius of curves	230 feet.	

ALLOWANCE FOR LOCOMOTIVES.

Coal—	Kilograms.
For each locomotive kilometre	4·00
,, hour in reserve shunting	30·00
,, ,, standing in steam without shunting	15·00
,, lighting up	60·00
,, carriage kilometre	0·60
,, loaded wagon (two axles) kilometre	0·70
,, ,, ,, (four axles) ,,	1·40
,, empty wagon (two axles) ,,	0·35
,, ,, ,, (four axles) ,,	0·70
Each hour shunting = 4 locomotive kilometres.	
Oil—	
For each six-coupled locomotive kilometre	0·040
,, four-coupled ,, ,,	0·035
,, hour shunting	0·100

NOTES.—100 kilograms of wood = 50 kilograms of coal.
Every ton of coal saved gains 5·00 lire (4*s.* 2*d.*).
,, kilogram of oil saved gains 0·50 lire (5*d.*).
,, ton of coal burnt extra costs 7·00 lire (5*s.* 10*d.*).
,, kilogram of oil used extra costs 0·70 lire (7*d.*).

The drivers generally saved on the above coal allowance, but used between 3 kilograms and 25 kilograms of oil in excess of above allowance.

APPENDIX III.

Bavarian Government Railways.

The Bavarian Government light railways are all of standard gauge, 4 feet 8½ inches, to allow of the passage over them of main-line goods wagons, but are under entirely separate management. The service is under the direction of the general manager, and on each branch or local railway an official is appointed who reports to a special department of the Director General of Railways' Office. The receipts vary between £2 and £12 10*s.* per mile per week (£100–£650 per mile per annum), of which on an average two-thirds are from goods and one-third from passenger traffic. On these lines there are a large number of stopping-places, which are divided into two classes, called principal and secondary. There is only one station, situated at the terminus of each line, where the branch manager resides. Of the one hundred stopping-places on branch lines fifty-one are principal and forty secondary, and there are nine stations. As the tickets are distributed on the trains, the machinery at the stopping-places is limited and reduced to the least possible amount. Frequently there is only a waiting-shed, and sometimes only a platform with a tablet showing the name of the stopping-place. There are no signals except at the entrances to junctions. Stations and stopping-places on lines where trains are worked by the staff are connected by telephone, and on these lines there is no fencing, and the level crossings are unguarded.

The passenger coaches and locomotives are of special types, lighter than those on the main line, and in order to reduce the number of vehicles there are only two classes. The carriages are of the Swiss or American type, with a central passage and communication with the baggage-car, and weigh about 6 tons each. On trains carrying the mail the baggage-car has a small compartment fitted up for the post-office official. The carriages are either heated by steam from the engine, or in mixed trains by a vertical boiler in the baggage-van. Lighting is effected by petroleum lamps. The "Heberlein" brake is used, and the rolling-stock is also provided with ordinary screw-brakes for use in case of need. There are two types of locomotives. Those for use only on lines having gradients not exceeding 1 in 150 have two axles coupled, and weigh about 18 tons in working order, and those for lines with gradients up to 1 in 40 have three axles coupled, and weigh about 26 tons loaded. On gradients of 1 in 100 the former have to take a load of 93 tons at a speed of 7½ miles per hour, and the latter 165 tons at a speed of 9 miles per hour.

The method of working these lines is of considerable interest, as on many of them the receipts, although very small, are sufficient to cover the working expenses. In 1893 the total receipts on the Bavarian Light and Roth-Greding Railways were £106,601 and £3,842, or £5 and £3 per mile per week respectively. The total expenditures were £55,588 and £2,636, or 50·26 per cent. and 68·61 per cent.

The branch manager is responsible for the due maintenance of the property as well as the working of his branch. He reports direct to the general manager through the office of Economical Railways. He has to take charge of the station where he resides, all the employees are under his orders, and in his office are kept the accounts of the branch. In case of an interruption to the working of the line he must, after despatching assistance, himself ascertain the cause on the spot. He controls the conductors and checks their accounts. Having the care of all the company's property he must pass over his branch on foot at least once a week, and satisfy himself that the points, permanent way and crossing places

are in good working order, making provision for renewals or repairs where necessary. He is also responsible for the proper maintenance of the road-bed and structures. He has to see that the locomotives are in charge of men well qualified to drive them, that the rolling-stock is properly distributed, in good condition, clean, and properly lubricated and lighted. He provides for all payments relating to his branch out of the traffic receipts. Every ten days he checks the balance of his cash office. The share of his branch in the expense of rolling-stock repair is furnished him monthly from the central-workshop returns, and every month he balances his books and sends a balance-sheet to the Director General of Railways.

The management of each train on the branch lines is entrusted to a conductor, who is responsible for the safety of the goods while on the train. He distributes the tickets during the journey, superintends the shunting at private sidings, and sees that all the train-hands assist. When at the terminal station he must, if required by the manager, assist by working in the office. The conductor is provided with a book of tickets containing stub and file so arranged as to show, by means of holes punched in them, the stations from and to which the passenger is travelling and the amount paid. By this method a simple and complete check is kept on these transactions. In the baggage-van are schedules showing the amount to be charged for the different classes and journeys for passengers, baggage and goods. Baggage is weighed by a weighing-machine in the baggage-van. Tickets in duplicate show the station from and to which the goods are being carried and the amount paid, one being given to consignor. Labels with a number corresponding to that on the ticket are attached to the goods, which are given up on arrival at their destination in return for the ticket. On arrival at a junction passengers and baggage are re-booked. For goods "carriage paid" at the junction the conductor acts as consignor, paying the freight for carriage on the main line and retaining that due for carriage on the branch out of the sum received when the goods were loaded on the train. At the end of the day the conductor makes out a report giving in detail all his transactions, which, together with the money received, counterfoils of tickets issued and checks withdrawn, he consigns to be checked by the branch manager, who then and there checks their accuracy. The conductor, besides performing all the duties inherent to the movement and safety of the train and care of goods consigned to him, provides directly for the distribution of passengers' tickets, receipt, taxing, and delivery of baggage and dogs, of goods and animals despatched between stations on the branch, exacting the amount due and compiling a complete account relative to such transport. The wages of a conductor are £50 per year, with an allowance for mileage.

The work at the stopping-places may be performed by men either employed or not employed by the Company. To the former are given between 3 miles and 4 miles of line to patrol. The man in charge provides for the receipt and delivery of goods, and assists in the shunting, loading and unloading of goods. These operations are facilitated and expedited by stopping the train so that the goods wagon is opposite the goods shed; and by means of planks the goods are wheeled on trucks from one to the other to avoid lifting. At stopping-places in charge of a man not in the Company's employ he is obliged to be at his post only half an hour before the train is due, to receive the goods to be forwarded or those coming by train. These men are authorized to charge consignors and consignees, according to a tariff fixed by the Company, for loading and unloading goods, the Company guaranteeing them between £15 and £20 a year of such charge. They receive whatever excess they make above that amount, and in this way are to a certain extent co-interested in the prosperity

of the railway. They give a small security as guarantee of their obligations. The receipt and delivery of goods are limited to certain hours in the day, having regard to local requirements, to allow the agent in charge of the stopping-place to perform his other duties for the receipt of trains and patrolling the length of line assigned to him.

Stopping-places are provided with tariffs showing the rates between points on that branch. For the cumulative service, or with other lines of the Bavarian railways system, the terminal station, where the branch manager lives, is provided with a complete set of tariffs. When the man in charge of a stopping-place has to despatch goods "carriage paid" to other lines, he finds from the terminal station by telephone the rate from the junction to the destination, and adds it to the rate for freight on the branch, which he has already ascertained from his tariff. In these cases the junction station acts as the intermediary, and, as described above, the work of the branch line is complete when it has handed over the goods and the amount received for freight from the junction to the destination. Men in charge of stopping-places send daily reports, which are compared and checked with those of the train-conductors. The terminal station then makes up its account and communicates with the junction station by telephone to ascertain whether they agree.

The driver must be capable of driving and maintaining his engine in good order, and of making such repairs as the appliances at the branch line's running shed admit. The locomotive and repair shops are situated at the headquarters of each division. He has to keep the record book of the respective engines, in which he notes all repairs executed and washings out. In addition to the duties incident to his office, he must, with the help of his fireman, before the departure of the train, and at intermediate points when necessary, examine and oil the carriages and wagons. The driver and fireman are enjoined to pay attention to defects in the road, and to immediately notify the branch manager of them, so that he, having at his disposal a limited number of platelayers, can send them to those points where they are most required. The cleaning of the carriages and preparation of the lamps is also carried out by the locomotive staff.

The fireman at the station and stopping-places must assist in loading and unloading goods, and act as pointsman. He must, in the absence of the brakeman, light the carriage-lamps, and light and extinguish the tail lamps of the train.

The duties of brakeman are performed by a porter from the junction or terminal station, who is employed when the train is longer than usual. Under the orders of the station-master or conductor, the brakeman must assist in shunting, attaching or detaching vehicles from the train, loading and unloading baggage and goods, and everything that the requirements of the service demand of them.

It is thus possible to perform the service in stations where there is only one employee, and provide in the ordinary cases for loading and unloading goods, and all the operations pertaining to the arrival and departure of trains. When the station-master, the conductor, fireman and brakeman all assist at these operations, the whole of the staff is equally employed and the service is economically performed. To show the actual results of such economical working, statistics of the Roth-Greding line are appended.

Roth-Greding Railway. (Gauge 4 ft. 9 inch.)

This line is 24·38 miles long, and was opened in 1883. Its construction cost £2,858, and its rolling-stock £269 per mile, the total cost being £3,127 per mile.

The permanent way consists of steel flange-rails, 29 feet 6 inches long, weighing 38·3 lbs. per yard between Roth and Eysoldeu, 13·6 miles, where they are laid on iron sleepers, and 44·3 lbs. per yard between Eysoldeu and Greding, 10·7 miles, where they are laid on iron longitudinals. This change of permanent way is due to the scarcity of material suitable for ballast, which in the first length consists of clean sand, and in the second of sand and clay mixed. This last arrangement allows a minimum quantity of ballast, while affording a firm bearing for the permanent way. The railway runs close to an ordinary road, and its levels follow as closely as possible the natural surface of the ground. The steepest gradient is 1 in 40, and the minimum radius of curve 650 feet, with the exception of a curve of 590 feet at the exit from Roth Station. The masonry works are few in number and of small size, constructed for the most part of rough stone. For carrying off the water cement pipes are extensively used, of circular section up to 2 feet diameter, and of oval section for larger openings.

The stopping-places are laid out as simply and economically as possible. There are no platelayers' huts, and the fencing both along the line and at all level crossings is entirely suppressed. The stopping-places and the station of Greding are connected by telephone. Between Roth and Greding there are seven principal and seven secondary stopping-places; generally they are placed close to a level crossing, and at those where there is no building a small wooden shed is erected to accommodate passengers waiting for the trains.

The rolling-stock assigned to this line consists of three Krauss locomotives with six wheels coupled; eight passenger carriages, of which three are second and third class mixed, and five are third class; three baggage-vans, with a compartment for the post-office; and two goods wagons. This rolling-stock forms three complete trains, of which two are in service and one in reserve. When, owing to heavy traffic of passengers or goods, other vehicles are required, they are borrowed from the main line.

The speed of the train is between 12 miles and 15 miles per hour. There are three trains each way in summer and two in winter.

The staff on this line consists of the branch manager, who is also station-master at Greding, an assistant and two clerks. The rest of the station staff consists of one pointsman at Roth, who, besides patrolling a length of the road, helps in the running-shed, lighting the fire in the locomotives, and filling the water-tank; and one pointsman at Greding, who assists in loading and unloading goods, cleaning the office and patrolling a length of road.

Three of the intermediate stopping-places are worked by employees of the Company, the others being served by men not in the Company's employ.

The staff of each train ordinarily consists of three men, the driver, fireman and conductor, unless the number of vehicles, owing to the gradients, require the assistance of one or two brakemen. Generally the trains consist of only two passenger carriages, one of second and third class mixed, and two of third class. The conductors have leave once every eight days, when their place is filled by one of the two office clerks. The whole line is therefore worked by thirty men, or 1·23 per mile of railway.

For the particulars respecting the Bavarian railways the Author is indebted to a report by the late Commendatore Biglia, and information supplied by the Director General of Bavarian Railways.

(Paper No. 2907.)

(Abridged.)

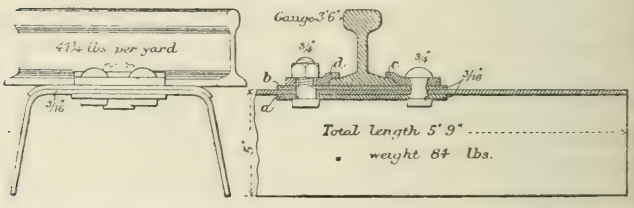
"Steel Sleepers in Queensland."

By JOHN ALFRED GRIFFITHS, B.Sc., Wh.Sc., A.R.S.M., Assoc. M. Inst. C.E.

THE Normanton-Croydon Railway,[1] North Queensland, is 94 miles in length, and was constructed in two sections. The first of these extended from the town of Normanton, at the head of the tideway of the Norman River, and about 50 miles from the sea, to a point about 36 miles further inland, and was laid with steel sleepers manufactured in the colony from imported materials. The second section, and the remainder of the line to the mining township of Croydon was laid mainly with steel sleepers manufactured in Glasgow, a short length being constructed with wooden sleepers.

Manufacture.—The sleepers[2] for the first section were of the

Figs. 1.



form and dimensions shown in *Figs. 1.* The body was bent from a $\frac{3}{16}$-inch plate, and was strengthened inside and outside at the rail-seats by plates *a* and *b* of the same thickness. The outer

[1] "Railways for Even Country, their Construction and Cost," George Phillips, Brisbane, 1888, and "Pioneer Railways for Queensland," by the same Author, Brisbane, 1892.

[2] See also "Report on the Substitution of Metal for Wood in Railroad Ties," E. E. Russell Tratman, United States Department of Agriculture, Bulletin No. 4, Washington, 1890, pp. 206–208.

fixed clips *c*, determining the gauge, of 3 feet 6 inches, are attached by two $\frac{3}{4}$-inch rivets, and the inner removable clips *d* by a single $\frac{3}{4}$-inch bolt with a grip-nut and pear-shaped neck fitting into corresponding holes in the trough-plates. There was no adjustment for varying the gauge, so that points and crossings had to be laid with wooden sleepers. None of the curves on the main line were so sharp as to require the gauge to be widened.

The steel plates and special bars for the clips were obtained from the Tredegar Ironworks, and the tender of the Toowoomba Foundry and Rolling Stock Company, Limited, for the manufacture of 80,000 sleepers, was accepted in October, 1887. The contractors' works being about 100 miles from the port, plans were prepared for special plant, which, by permission of the Queensland Railway Commissioners, was erected at Wooloongabba near the South Brisbane Railway wharf. It was compactly arranged under a large shed, so that the plates were moved from one machine to another with as little lifting as possible. The plates and bars were delivered by the Government to the contractors in trucks, and they were at once transferred by a narrow-gauge line and stacked. Owing to the arrival of plates in large shipments at intervals of several weeks it was impracticable to unload the plates directly from the trucks to the machines. The plates were first examined for defects, and the holes for the clips and the two rail-seats punched. They were then bent cold, the press making between ninety and one hundred and twenty strokes per hour, and the plates being guided by pins in the pear-shaped bolt-holes. The total number of plates bent was 80,605, and only about a dozen failed in the cold bending. Two or three plates, however, were so hard that they cracked sharply with but little permanent set. The smaller components were prepared at the same time at other machines. The fixed clips were riveted on, and the completed sleepers, in sets of thirty at a time, were dipped into a boiling composition of gas-tar and Trinidad bitumen, and then stacked for shipment. The number of men employed varied between forty and sixty according to the extra labour required for handling shipments.

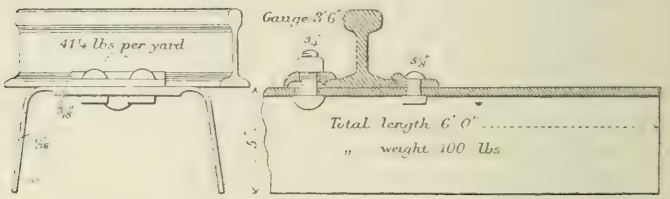
The total cost of the finished sleeper was high, being augmented by several causes. The total number of sleepers paid for was 80,626, a few plates having been destroyed in the manufacture of the sleepers, and an unknown but not large number lost overboard during transshipment. The final cost per sleeper, of 84 lbs. average weight, was—

	d.
Imported materials, including plates, bars and bolts . .	53·62
Freight and charges, England to Brisbane	8·28
Toowoomba Foundry Company's contract for forming, providing rivets, and coating	21·50
Freight and lighterage, Brisbane to Normanton . . .	22·27
Compensation for defective materials, &c.	2·94
,, to shipping contractors	1·93
Total cost	110·54

This cost could be reduced fully 20 per cent. in the purchase of materials and by avoiding re-shipment.

The sleepers used on the second section were slightly longer and heavier than those for the first section, the actual dimensions being as shown in *Figs. 2.* Instead of strengthening the rail-seats

Figs. 2.



by extra plating, the whole of the top of the trough was rolled $\frac{3}{8}$ inch thick, the vertical sides being $\frac{5}{16}$ inch as before. These sleepers were made by Messrs. P. and W. MacLellan of Glasgow, and shipped direct to Normanton. Their final cost was—

	d.
Messrs. P. and W. MacLellan's contract	90·00
Freight, lighterage and charges	30·05
Total	120·05

The cost of preparation in Scotland was probably increased by the substitution of hot for cold pressing. Under more favourable conditions, steel sleepers of these patterns could probably be delivered at a good Australian port for about the following prices:—

	84 lbs.	100 lbs.
	d.	d.
Steel at $\frac{1}{2}d.$ per lb.	42	50
Forming and coating	21	18
Freight	9	10
Total	72	78

And these costs would admit of still further reduction in the case of larger contracts.

Laying the Sleepers.

The route of the railway is so even that, with the exception of a few short lengths, amounting in all to about 2 miles, no work of the nature of grading was required.

Preparing the Road-bed.—The climate is dry, and the stunted vegetation was easily cut down and cleared for a width of 66 feet. In the centre, for a width of 10 feet, the stumps and roots were grubbed out or cut off 6 inches to 8 inches below the surface. In the more compact loamy soil the road-bed was ploughed 6 inches to 8 inches deep for a width of 8 feet, the harder clods being broken up with picks, while in the light sandy loam the surface was merely loosened by scarifying. After the ploughing or scarifying, the formation was levelled and compressed by a roller about 6 feet long by 3 feet in diameter, weighing about 3 tons, and formed by filling a sheet-iron cylinder with concrete.

Distributing Materials.—At the wharf terminus near Normanton a gang of men was employed transferring materials from the lighters into trucks. A train-load was usually made up with three long trucks of rails, five or six short trucks with sleepers and fastenings, and one or more water-trucks. Water stations were far apart and the men were entirely supplied by train. One train per day usually sufficed, leaving Normanton soon after daylight, and travelling to the head of the road at a speed of 15 miles to 20 miles per hour. This train ran to the extreme end of the laid rails, was quickly unloaded, and returned at once to Normanton. The water carried on the train was run out into low-level tanks at the nearest camp. One locomotive sufficed for haulage, even up to the Croydon terminus, as the delays in the shipments of sleepers rendered it impossible to organise any expeditious campaign of work.

Laying and Linking.—The hand-trolleys used had the ordinary light frames and loose axles. They were fitted with rollers at each end on which four pairs of 26-foot rails rested longitudinally, and side bars of wood supported the corresponding forty-four sleepers. Four men were engaged in loading, and three trolleys and one horse conveyed materials from the stacks, where the train was unloaded, to the head, the average lead being 20 chains to 25 chains. The fastenings were separately carried ahead in boxes holding between 2 cwt. and 4 cwt. Previous curving of rails was nowhere necessary. The loaded trolley was drawn to the end of the last pair of rails laid, and six men working in pairs lifted off eleven sleepers and placed them in position between two

marked battens. The rails were laid at both sides simultaneously, and the fishplates to the last pair of rails were loosely put on. The trolley was then drawn ahead for another rail-length, and the process repeated until the four pairs were laid, when the empty trolley was lifted off the rails to one side, to allow a second loaded trolley to be drawn ahead. The empty trolley was then replaced on the rails and taken back for a fresh load. Behind the working trolley about eight men were engaged in completing the fastenings; and the trolley traffic over this part helped to force the sleepers into the soil.

Lifting, Ramming and Straightening.—These operations occupied about twenty-five men, who worked about ½ mile to ¾ mile from the head of the road, but this interval of imperfect road did not prevent the passage of the material train to the head. The rails and sleepers were lifted by double screw-jacks, two to each rail-length, from 2 inches to 5 inches, according to the settlement under the trolley traffic. No attempt was made to set the rails to any calculated gradient or formation height, the natural surface being simply equalized with boning-rods over a length of several chains. It was intended that the sleepers should finally rest with about half their depth below the original surface. Two men operated the lifting-jacks, and other men working in pairs shovelled soil against and into the ends of the raised sleepers, and packed it tightly under the troughs with wooden rammers. A level-bar was used to keep the rails at a uniform height, and the line was straightened in the usual manner. The adjustment and straightening were completed by a group consisting of the ganger and assistant and three other men. The plate-laying was then finished, and but little attention was needed until the wet season.

Rate of Work.—The sleepers manufactured at Wooloongabba were shipped as fast as they were finished, and the laying-in commenced at Normanton on the 2nd July, 1888. Short lengths of the line were laid at the rate of ½ mile per day, but owing to various delays in shipment and lighterage in the Norman River, the actual progress on the first section, completed on the 14th January, 1889, averaged only about 5 miles per month. This delay in transit was a main factor in determining the manufacture of the sleepers for the remainder of the line in Europe. The first shipment, however, did not arrive at Normanton until the 30th July, 1890. Meanwhile, it was decided to continue the laying with wooden sleepers, as nearly as possible under similar conditions to the steel sleepers. Thirteen miles were so laid, partly with sawn iron-bark sleepers, and partly with half-round

blood-wood sleepers. The laying-in of the sleepers from the Glasgow contract was commenced on the 22nd September, 1890, at 43 miles, and the rate of progress on the second section averaged but 6 miles per month, the rails being laid to Croydon Station on the 9th July, 1891. The rate of work, excluding total stoppages from flood and delayed materials, averaged 32 chains per day, with a maximum of 52 chains.

Cost of Laying.—The labour employed was one team of twelve to fourteen bullocks, one horse, and fifty to seventy men and boys. The ruling rates of wages per day of eight hours were 10*s.* for men, 8*s.* for boys, and 1*s.* extra for gangers. The average cost of the work in the earlier stages was £71 6*s.* 6*d.* per mile; the cost of the best day's work at the end of the second section, when 52 chains were laid in one day, was reduced to £58 13*s.* 4*d.* per mile. In contrast with these figures, the cost of laying the short portions with wooden sleepers was nearly 50 per cent. greater for labour, with the additional disadvantage of the future cost of relaying the wooden sleepers, probably from five to six times during the life of the steel sleepers.

The total cost of the railway is estimated at £2,162 per mile for materials used, labour in construction, surveys, plans, and supervision; the balance of the capital expenditure, amounting to about £600 per mile, being for station accommodation, rolling-stock, surplus material, and land resumption.

Maintenance.—In considering the efficiency of this type of railway, it must be borne in mind that the limited traffic between the mines and the port necessitated every possible economy in first cost, and only sufficient stability to carry the ordinary rolling-stock of the colony at moderate speed in any weather during which traffic could be brought to the stations, and so long as the rails are not too deeply covered by flood-water. Until April, 1895, the ordinary traffic had been amply provided for by three trains each way per week, with a few extra trains for suburban traffic for a few miles from each terminus. The intermediate country is uninhabited. The locomotives employed are tender engines 45 feet long over all, 45 tons total weight, with six-coupled drivers They can haul 250 tons on the level, and 150 tons on the short 1 in 50 gradients near Croydon. Traffic statistics, compiled from the official reports of the Queensland Railway Commissioners, are given in the Appendix.

Although the route appears for the greater part to be perfectly flat, the level shows a steady rise from the Norman River bridge, at 14 miles, towards Croydon, with maximum gradients of 1 in

1,000. Yet, in protracted rains, water flows across the line in broad sheets, occasionally several feet in depth and with fair velocity, showing that any attempt to raise the line above the general surface by embankment, or even by the usual thickness of a ballast foundation, would have necessitated considerable and costly waterways. At the time of the survey of the country for the selection of route, there was no trace of any line of drainage, yet a river exists in wet weather, and then the traffic has to be carried on with the wheels running in water. The slight vibration of the road causes a little water to be pumped in and out of the sleeper-trough, and to prevent excessive washing away of the loose soil, some harder material has been used as packing where water accumulates. The total quantity thus used during the five years of working amounts to about 22,000 cubic yards for the whole 94 miles, the greater portion being used with the wooden sleepers. When these latter portions were first laid, about 100 cubic yards per mile of shingle ballast were used in the packing; since October, 1891, the quantity has been greatly increased, and the whole of the wooden sleepers are now fully ballasted and boxed up throughout. The advantage of thus using ballast, averaging but a few cubic yards per chain, with the steel sleepers is obvious when the character of the soil is considered. Any rainfall, sufficient to thoroughly wet the soil, converts it into running mud; and during the protracted rains, this takes place to a depth of 12 inches to 20 inches, when ordinary locomotion of men or beasts is impossible until the soil dries. Over this surface, however, the steel sleepers support the train satisfactorily. The depth of the trough being 5 inches, the soil becomes firmly consolidated within it by the end ramming, and an entire set of two rails with eleven sleepers may be lifted bodily with the adhering blocks of compressed soil and turned over. The dead weight of the permanent way is thus increased to over 4 cwt. per lineal yard —comparable with that of a ballasted road of wider gauge— and this contributes greatly to stability. At the same time the compression spreads downwards, so that the deeper soil is less disintegrated by the rainfall. After the ganger and his construction party have completed the packing and straightening, the solidity of the line is such that the traffic causes little disturbance of the rail-level; but the settlement in flood-time entails considerable labour. This was a source of much anxiety during the first wet season of 1890–91; but it was found that those sections which had been thoroughly packed after the first flood gave comparatively little further trouble.

The first section was constructed at the end of a period of drought (1888–89), the usual wet seasons of 1888 and 1889 having been attended by but a few thunderstorms which never thoroughly soaked the soil, but rather tended to consolidate the track. Heavy rain began at the end of December, 1889; by the 2nd of January, 1890, traffic was interrupted at 9 miles and 11 miles, and entirely stopped on the 4th by a depth of 13 feet of water over the Norman Bridge, which, with many miles of railway at each side, continued under water until the 8th of February. As soon as the water subsided sufficiently to clear the rails on the bridge, a pilot engine ran over the whole of the road laid with steel sleepers without any disturbance of the road; but at the end of the section a temporary reversing triangle had been laid without ballast on nine half-round wooden sleepers per 26-foot rail, and on entering this siding the road sank under the weight of the engine until the rails and sleepers disappeared in the mud, and the cylinders of the engine touched the surface. The ground alongside the main line was equally soft to that near the siding, but the steel-road carried the load perfectly, and the run back to Normanton was made at a speed of 20 miles per hour and upwards. Ordinary traffic was resumed next day without special repairs to the line being necessary, but traffic was occasionally interrupted during February by floods. This section was well packed in the dry months of 1890 during the construction of the second section. A portion, laid in dry weather, was opened for traffic before the next wet season began, and the cost of its maintenance during the year 1890–91 was £153 2*s.* 7*d.* per mile per annum, requiring nearly one man per mile, whilst the cost of maintaining the first section during the same period was but £79 11*s.* per mile, requiring only 0·47 man per mile. This illustrates the extra cost of maintenance immediately after the first flooding of a section, and this extra cost should perhaps be charged to construction. The last part of the second section was laid mainly in dry weather, and in the two following seasons, 1891–92 and 1892–93, the rainfall was slight, so that the last portion was not flooded until the third season, 1893–94, when the floods were unusually prolonged. On the 2nd April, 1894, it was found on the worst part of this length that the tops of the sleepers had in many cases settled flush with the ground; but on the worst places on the older length no serious subsidence was noted.

On other lines in the colony, about 2,400 miles in length, with standard ballasted formation and thorough artificial drainage, the casualties from floods, &c., during the season 1893–94 are re-

turned[1] as costing £12,777 for repairs; but the extra cost on the Normanton-Croydon railway during four months' wet season was so slight that the special expenditure on this head is returned as nil. During this season the hardwood sleepers were suffering from decay and white ants, and one hundred and thirty-nine were renewed after a life of only three years. Some of the iron-bark sleepers at Haydon were badly attacked by the white ants before they had been one year in use.

The cost of maintenance for each season since the opening of the line, as given in the official returns, shows a steady decrease to a minimum of under £62 per mile per annum. The maintenance staff now consists of one officer in charge of traffic and maintenance; one inspector of permanent way, and thirty-four labourers. The detailed inspection is carried out by each ganger upon a manual tricycle, enabling long distances to be attended to by each small gang. The wages, at the rate of 10*s.* per day, are much higher than in the more temperate parts of the colony, where the average cost of maintenance, except in a few isolated short branches, is between £100 and £150 per mile, at the lower rates of 6*s.* 6*d.* to 7*s.* 6*d.* per day.[2] Consequently it is probable that, in similar circumstances, the maintenance of the steel-sleeper road would be half, or less than half, that of a wooden road.

Wear and Corrosion.

The traffic has been so light that as yet the wear is inappreciable. At a short length of line where a salt-swamp, liable to submersion at spring tides, is crossed, some corrosion has taken place, but not more than has happened in other countries where metal sleepers have been laid on unsuitable material, such as coal-cinders.[3]

Conclusion.

The whole of the surveys, plans and works were carried out under the direction and superintendence of Mr. George Phillips, of Brisbane, in whose office the Author was principal assistant engineer, and to whom he is specially indebted for information and assistance in preparing this Paper. The plate-laying and construction was in charge of Mr. A. S. Frew, resident engineer.

[1] Annual Report of the Queensland Railway Commissioners, 1893–94, p. 43.

[2] Annual Reports of the Queensland Railway Commissioners. Table No. 13.

[3] "Pioneer Railways for Queensland," George Phillips, Brisbane, 1892, pp. 78–87.

The whole of the work was carried out by day-labour at the cost of the Queensland Railway Commissioners, who paid monthly wages by their own pay-master on the certificate of the Superintending Engineer. The machinery and plant at Wooloongabba was laid out from special designs of the Author for the contractors, and the manufacture of the sleepers was under the inspection, on behalf of the Queensland Government, of Mr. Henry Horniblow, locomotive engineer.

The Paper is accompanied by three sheets of drawings, from a selection of which the *Figs.* in the text have been prepared.

APPENDIX.

Statistics.

	Financial.							Maintenance.			
Season.	Traffic Mileage.	Total Capital Expended.	Traffic Receipts.	Working Expenses.	Earnings per Train-Mile.	Percentage of Net Earnings on Capital.	Rainfall.	Maintenance per Mile.			Labourers per Mile.
		£	£	£	s. d.			£	s.	d.	
1889 .	36	107,468	383	500	3 9	Loss	Very light		..		0·66
1889–90	36	118,722	2,085	5,086	3 7	Loss	Heavy		..		..
1890–91	57	184,617	7,758	7,660	5 9½	0·053	Heavy	102	3	5	0·65
1891–92	94	265,713	21,222	12,513	12 10¼	3·278	Light	81	9	9	0·48
1892–93	94	270,368	20,230	12,401	9 10½	2·896	Light	76	18	7	0·45
1893–94	94	271,611	14,757[1]	10,301	8 5¼	1·641	Very heavy	61	14	7	0·36
1894–95	94	..	..	..	..	..	Heavy		..		..

[1] On the 1st of January, 1894, the rates for all classes of traffic were reduced to about two-thirds of their previous amount, to assimilate them to the southern tariff.

(*Paper No. 2916.*)

"Bridges on the North-West Argentine Railway."

By Robert Henry Frederick Stuart, M. Inst. C.E.

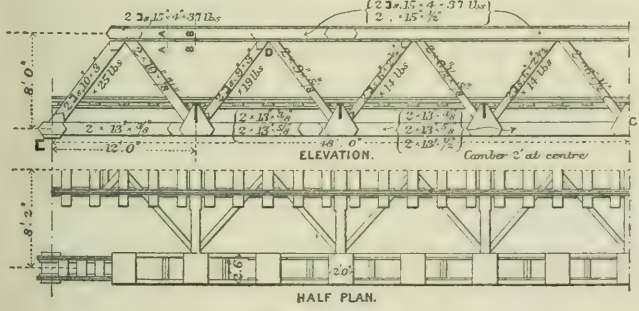
The North-West Argentine Railway lies wholly within the Province of Tucuman, Argentine Republic. The gauge of the line is 1 metre, and for about 60 miles of its length it runs parallel with the Aconquija Range of mountains; its distance from the foot of the first slope varying between 1 mile and 10 miles. In this length of 60 miles, fourteen rivers, varying in width between 30 yards and nearly 400 yards, are crossed. The North-West Argentine Railway joins the Central Cordoba Railway at La Madrid, 525 miles from Rosario, the port to which the railway material was consigned; and at Cordoba, between Rosario and La Madrid, there is a break of gauge from 5 feet 6 inches to 1 metre. All the material, therefore, other than that obtained in the locality, was subject to the delay and expense not only of a long land transport, but also of transshipment.

In accordance with the terms of the concession, the line should have been completed in November, 1888, but the Provincial Government of Tucuman granted an extension, first of nine months and subsequently of one month for the track to be available for traffic between La Madrid and Tucuman, and the permanent bridges were to be completed as soon after that time as possible. By the end of May, 1889, three bridges, or seven spans of the total of fifty-four, had been completed. An arrangement was then made between the Company and the contractors by which the Author carried out the remainder of the work. By expediting the delivery of the material from Rosario and reorganising the work, 3,275 cubic yards of material were sometimes excavated under water, 2,100 cubic yards of brickwork in cement built, and ten complete spans erected, during a single month. The working season in the rivers is between the beginning of May and the end of October, so that it was necessary for all the foundations and the greater part of the abutments and piers, to be completed by the end of October, 1889; otherwise the completion of any unfinished foundations might have been delayed until the following

May. The limit of intensity of stress, 3·81 tons per square inch, enforced by the Argentine Government is unnecessarily low. Although the North-West Argentine Railway is of 1-metre gauge, the bridges were designed with a view to its possible conversion to the 5-foot 6-inch gauge.

Design of the Spans.—The design of the bridges had to be such that the work of erection could be rapidly carried out. Most of the rivers had low banks, and in two cases only would it have been practicable to adopt deck bridges. The geographical position of the railway rendered it undesirable to have more than one type of span; any duplication would have caused serious delay, as, to ensure continuity in the work, it was necessary that the parts of the spans should be interchangeable. It was therefore decided that one type of span should be adopted, the trains running

Figs. 1.



MAIN GIRDER.

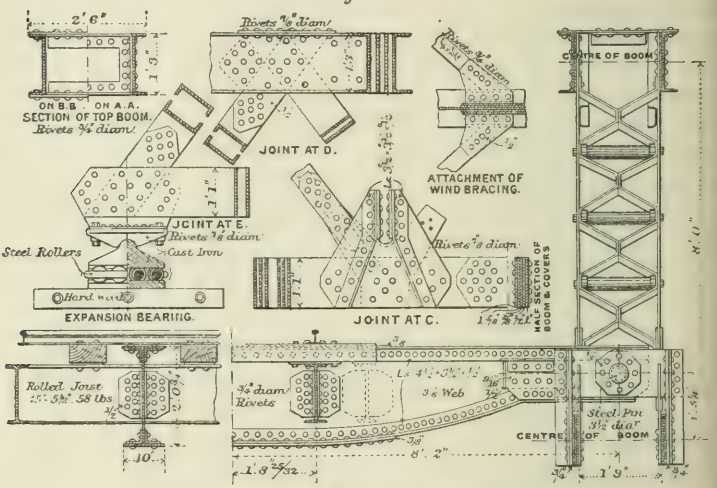
Scale, $\frac{1}{10}$ inch to 1 foot.

between the girders, so that the maximum clear space should be available for the flood-levels of the rivers, with a minimum height of approach embankments. To ensure speed and economy it was found that the girders could not be riveted *in situ*, as this would have necessitated either a considerable time or a large outlay on plant, as well as a great number of sub-contractors to work simultaneously, none of which conditions were possible. The main girders had therefore to be of such a size that they could be erected in a convenient yard, or yards, and transported complete to their respective situations. Girders of about 96 feet in length and 9 feet in depth over all, were convenient for this, as they could be carried on three platform cars.

The design of the main girders is shown in *Figs. 1.* They are of 96 feet span between the centres of the bearings, the depth between the mean fibres of the booms being one-twelfth of the

span, or 8 feet. The length of 96 feet not only corresponded with the width of the rivers, but was also the most convenient length for the work of erection. Of the fourteen rivers, five required one span; three, two spans; one, three spans; one, five spans; two, six spans; one, ten spans; and one, thirteen spans; involving the construction of forty piers in all. In Europe it would probably have been preferable to have had four lengths of spans, say 96 feet, 192 feet, 240 feet and 288 feet. Only nine piers would then have been necessary, and more economical girders could have been designed. The time necessary for their erection in the Province of Tucuman would, however, have been prohibi-

Figs. 2.



Details of Main and Cross-Girders.

Scale, ¼ inch to 1 foot.

tive. The girders are set 16 feet 4 inches apart, from centre to centre, the clear running space between the inside edges of the booms being 13 feet 10 inches. The rolling load per span was 128·57 tons, being fixed by the Government at 3,000 lbs. per foot of span. The dead load of the span, including the track, was 56 tons. All forgings and special forms of plates, etc., were avoided as far as possible, and an attempt was made to conform with the conditions of uniform stress. To effect this the cross-girders are connected by pins with the main girders, which are supported on rockers. Details of the main and cross-girders are shown in *Figs. 2.* The reference letters are similar to those shown in *Figs. 1.*

The booms, the web, and the grouping of the rivets were so designed that the respective mean fibres of the former intersected in the centre of gravity of the latter. The primary reason for the adoption of the isosceles type of truss, in preference to the Whipple-Murphy, was that the joints between the webs and booms are less cramped and the grouping of the rivets is easy and satisfactory. An investigation of the theoretical weight of metal necessary for the main girders in each case, assuming 5 tons per square inch intensity of stress in tension and 4 tons in compression, showed that the weight of the Whipple-Murphy was about 4 per cent. greater than the isosceles type. The rail- and cross-girders were designed for the wheel-base and weights of a locomotive in actual use on one of the broad-gauge Argentine Railways. The maximum stresses in the compression and tension members of the web and of the booms varied respectively between 50·47 tons and 14·75 tons, 50·47 tons and 14·75 tons, 60·57 tons and 138·44 tons, and 30·29 tons and 134·11 tons at the ends and centre of the span. These total stresses correspond with intensities of stress varying between 3·03 tons and 1·58 ton, 3·62 tons and 2·88 tons, 2·46 tons and 3·49 tons, and 3·22 tons and 3·69 tons per square inch respectively.

All rivets in joints are $\frac{7}{8}$ inch in diameter; in calculating the bars in compression the rivet-holes were not taken into account. The centre bars of the web are each subject to an alternate total compressive stress of 5·35 tons, and were therefore counterbraced. By connecting together the channel-bars composing the struts, their greatest width became available to resist flexure, a factor of safety of 5 being given in the worst cases. The actual weights of the spans are :—

	Tons.	Cwts.	Qrs.	Lbs.
Two main girders	34	13	0	14
Seven cross- „	5	19	0	0
Fourteen cross-girder bearers and pins	3	15	0	24
Sixteen rail-girders	4	19	2	0
Twenty-eight rail-girder fastenings .	0	10	0	0
Wind bracing	1	6	2	25
Fastenings of track to rail-girders . .	0	10	3	5
Four bearings for main girders . . .	2	2	3	20
Four bed-plates for rail-girders . . .	0	1	2	24
Total . . .	53	19	0	0

The weight of the track is about 4 tons 16 cwt. 2 qrs. per span; so that the weights of the bearings, bed-plates and the shoes at the ends of the main girders, about 15 cwt. 2 qrs. 14 lbs., borne directly by the abutments, being deducted, an actual dead weight

of 55 tons, 15 cwt. 26 lbs. is obtained. The amount allowed in the calculation was 56 tons. If the limit of stress had been 4 tons per square inch in compression and 5 tons in tension, instead of 3·81 tons, the span could have been designed to weigh about 45 tons complete.

The cost of the wrought-iron work was £13 15*s.* per ton, and the total cost per span was £793 8*s.* 10*d.* f.o.b., including the bearing apparatus and the steel rollers.

Bridge Sites.—With two exceptions the rivers had low banks, and the highest flood-levels of all were easily ascertained. In one case, that of the River Lules, the river-bed lay on an "alluvial fan" formed by the material washed out of the gorge worn through the hills by the river. The bed of the river was higher than the general level of the country, the ground rising to it on each side with a gradient of 1 in 150. The rivers have a rapid flow, their fall varying between 1 in 100 and 1 in 2,000. They run almost dry in winter; but are subject to sudden floods in summer, which is the rainy season of the country, their levels rising rapidly 6 feet or 8 feet. The rainy season is variable, but generally commences in November and ends in April.

The choice of bridge sites presented some difficulty and necessitated a careful study of the rivers. With few exceptions the river-beds change within certain limits, but it was generally possible to find some point where these limits were well defined and the width between them a minimum; and this point, if reasonably near, was chosen for the bridge site and the railway was traced to suit it. In the case of the largest river, the Gastone, which was the most subject to change of bed, there was little choice of site, as it was close to a town where the position of the line was fixed by the Government. A convenient and reliable site was, however, found, which seemed to be unattacked by changes of the bed, at a point where an island, flooded in the heavy rainy seasons, covered about one-third of the total width. As the south banks were of sandy soil similar to other banks of the river that had been washed away, some anxiety was felt in placing the abutment upon them. The bridge has, however, now been erected five years, and has been tried by heavy floods, the bed of the river having varied considerably; but the approach embankments have never been in any danger.

Foundations.—The river-beds were found to consist of sand, gravel and stones mixed, to a great depth; or of these materials overlying what is known in the country as "tosca." This consists of hard clay enclosing veins of limestone, which appears to

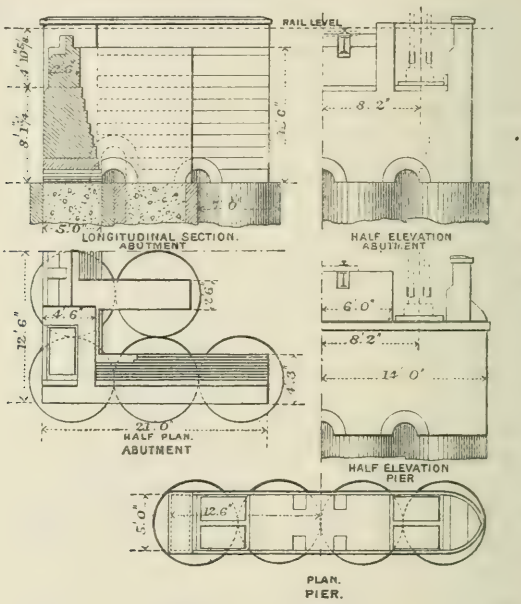
correspond with the ramified kunkur of India. The tosca is reliable for foundations; it occurred at depths varying between 10 feet and 15 feet below the surface. In the case of the River Lules, the trial excavations disclosed that the original surface of the land lay at about 17 feet below the bed of the river. The river ran almost dry in the winter and the excavations could be made dry. In all the other rivers, even when apparently dry, there was a strong flow of water immediately below the surface, necessitating constant pumping to obtain foundations.

For economy and simplicity of work, it was necessary that either brick wells or iron cylinders should be employed. Brick wells were adopted as the more suitable. All the work executed remained as permanent work, and Portland cement and iron rods were the only imported articles required. Cast-iron cylinders offered no advantages and many inconveniences, owing to the delay in obtaining them from England, loss from breakage, cost of transport, accurate sinking between guides, etc. Bricks could be made at almost any point on the line; thus, not only was a cheap material obtained, but the cost of transport was reduced to a minimum. There was no difficulty in making local contracts for bricks as all the inhabitants are accustomed to their manufacture, and wood fuel was plentiful. The bricks measured 12 inches by $5\frac{3}{4}$ inches by $2\frac{3}{4}$ inches, and cost about £2 per thousand, placed at the side of the track. Excellent sand was obtained in the rivers, and the Portland cement was imported from England.

The depth of 20 feet below the lowest level of the river-bed was adopted for the foundations in the cases where the tosca was not met with. This depth suited the power of the centrifugal pumps employed, and, from observations of the scour in the rivers, appeared quite safe. The foundations received a severe test in the River Gastone, where, during one of the floods, part of the river above the bridge changed its course, ran along the comparatively level ground between the two rivers formed by the island, and rushed back to the real bed of the river, down the slope of the bank close to the bridge. The current struck one of the piers obliquely with a fall of about 1 in 10, and scoured out a hole 6 feet deep in the front and on the reverse side of the pier, and somewhat less on the side of impact. Nothing could be done during the heavy flood, but afterwards the hole was filled with large flour-bags filled with weak cement-concrete, and no further scouring occurred. The bridges have now undergone the test of five rainy seasons, and all the foundations have proved satisfactory.

Abutments and Piers.—The details of the abutments and piers are shown in *Figs. 3.* The upper portions in both cases rest on groups of brick wells of 7 feet outside diameter, 12 inches thick, and filled with cement-concrete. In the example shown, the abutments have a group of ten wells, four for the face, two at each side for the return walls, and two in the centre for buttresses. It was considered advisable to add the latter, but, in the case of lower abutments, they were dispensed with.

Figs. 3.



ABUTMENTS AND PIERS.

Scale, $\frac{1}{10}$ inch to 1 foot.

The piers are 5 feet thick and rest on four wells, similar to those for the abutments. The wells were as a rule completed to a level but little above the bed of the river, but in cases similar to that shown, they were prolonged so that the height of the pier should not exceed 15 feet to the rail-level. Jack arches were built over the points of contact of the wells to support the superstructure, and were closed by the wells being prolonged below them, up to the soffit. Cement mortar was employed, composed of one part of Portland cement, and three of clean river sand. The cores of the wells were filled with cement-concrete, composed of

one part of the cement mortar dry, and six parts of broken brick or gravel, or both mixed. When the proper depth of foundations had been reached, the water was allowed to rise to its full height in the wells, and cement-concrete was then lowered in covered buckets, emptied, and rammed. The work was carried out in layers of about 2 feet thick at a time, intervals being allowed for the cement to settle.

In the case of the River Lules wells were not necessary, excavations being made in the dry to the depth required and the piers built up in them. A sufficient quantity of small boulders was gathered in the proximity of the bridge, to replace bricks for the parts of the abutments and piers between the foundations and the surface of the ground. The upper parts of the piers were, in this river, made 6 feet instead of 5 feet thick, on account of the danger from the large trees brought down by the floods. This danger exists in all the rivers, and none but masonry piers would have been suitable. The Government railway bridges over the same rivers, but 20 miles further away from the mountains, have had to be almost entirely renewed by reason of the destruction of their iron piers.

Sinking the Wells.—The bottom curbs of the wells were first laid in position, the sites having been previously roughly levelled; any stream of water existing in the river-bed interfering with this was diverted sufficiently for the work to be carried out. The tie-rods and upper curbs were fixed in place and the drum completed with the brick in cement. The curbs were made of a native wood, "pacara"; the triangular form of cross section of the lower curb gave a sufficient cutting-edge for the nature of the bed which had to be traversed. The first drums were generally built about 10 feet high, and were plastered outside to present a smooth and water-tight surface. When they were all built in position they were allowed to dry as long as circumstances would allow before sinking operations were commenced. Where wells had to be sunk before the brickwork had set, the result was never satisfactory; the wells lost their shape, the water penetrated through the openings of the joints, shorings had to be inserted, and the work was dangerous to the men excavating inside. These difficulties were not so considerable in the piers as in the abutments, where, owing to the slope of the banks, the rear wells had to sustain the pressure of the earth, the tendency being to flatten the wells against one another. When it became necessary to push forward the work rapidly, and there was no time to allow the drums to dry, the abutments gave considerable trouble; and,

although the foundations were ultimately all reached without accident, there was in some cases considerable danger of collapse. The thickness of the abutment-wells was therefore increased from 12 inches to 18 inches, and the work was more satisfactory although the working space inside was necessarily reduced. The wells 12 inches thick are satisfactory if the brickwork has time to set. To sink the wells, a centrifugal pump, driven by a portable engine situated in the bed of the river, was placed over one of the groups, and a man excavated inside each well. As a rule one pump was sufficient for a complete group of wells of an abutment and a pier, but sometimes, even for a pier, it was necessary to use two pumps.

Centrifugal pumps by English makers were employed, varying between 5 inches and 8 inches in diameter; the portable engines ranging between 8 HP. and 12 HP. The work was accomplished with fourteen engines and pumps, their cost on the work being about £7,250. They were afterwards partly utilized for the working of the line, and the rest were sold to sugar-factory and saw-mill owners. The well in which the pump worked was kept a little lower than the rest in the group, and all were weighted with rails to sink them. The man excavating in the well filled a wooden box which was raised by a light winch; where the space above was cramped, a bucket instead of a box was used and simply hauled up by hand. When the first drum or length of well was sunk, the pump and rails had necessarily to be removed. The top curb was also removed, a new length of tie-rods was attached to those already in the work, and a new drum of about 6 feet 6 inches in diameter was constructed as before. The bricks were very porous, absorbing as much as 25 per cent. of their weight of water when immersed; by keeping the best bricks for the work on the face and by pointing broadly and well with mortar gauged one of cement to one of sand, the work was found to be satisfactory.

Erection of the Spans.—The abutments and piers having been completed to the necessary level, two derricks were raised, one on the first abutment and the other on the first pier, arranged so that they could be dipped towards the temporary track in the bed of the river, parallel with the bridge. The girders, on a train of wagons, were brought alongside the bridge on the temporary track, hauled off greased rails laid on a staging of sleepers, and pushed almost up the abutment and pier work. Iron stirrups were fixed under the ends of the top booms and the tackle was hooked on, the derricks having been previously dipped. The girders were then

tilted up and raised, the derricks hauling on until they hung over the bearings prepared for them, on to which they were lowered. The bearings used for this purpose were the lower saddles or "knuckles" of the permanent bearing apparatus. The girders were brought to their ultimate positions over the knuckles by two 10-ton hydraulic jacks, one at each end, the pairs of girders being utilized to steady one another by an arrangement of lashing the top booms together. The motion being slow, the lashing could be accommodated to it. When the limit of one knuckle was reached, another was placed in front of it, and so on. The bearing apparatus to receive the girders was accurately placed and levelled beforehand, an even bed being obtained and small differences of level adjusted by interposing layers of tarred canvas between their under sides and the wooden bed-plates. The jacks proved very satisfactory owing to their easy manipulation and the facility of applying their force; they were simply attached to the knuckles by sling-chains. The pin-connections between the cross-girders and main girders allowed the former to be rapidly fixed. The riveting of the rail-girders and wind bracing was simple; in cases of urgency they were left for the time, the bridge being at once utilized by laying a number of rails over the cross-girders, and running a temporary track on these.

Plant used in the Erection of the Bridges.—In addition to the ordinary tools and small plant, such as smiths' and riveting forges, planks, ropes, tackle, etc., the heavy plant was limited to one portable hydraulic riveter, on a trolley to run on 6-foot $6\frac{3}{4}$-inch gauge, costing £390; two steam cranes, to lift 5 tons each, provided with double sets of wheels and axles, one for 7-foot gauge, when used for bridge-work, and one for 1-metre gauge for transport, costing £420 and £550 respectively; and eight 10-ton hydraulic jacks, costing £4 each. The cranes were afterwards taken into use on the railway as breakdown and general service cranes. Rails and hardwood sleepers were utilized in making the temporary bridges and the staging between these and the permanent work. This material was subsequently put into service in the track.

Exceptions to the Mode of Erection.—The girders of the bridge shown in the *Figs.* were not erected in the ordinary manner. The floods rendered the temporary bridge dangerous at the time when the brickwork was ready to receive the girders, and it had to be removed. As it was important to bridge this river, a series of trestles was made and placed in the river-bed between the abutment and the pier, a few rails being laid over them to

allow of packings of sleepers being placed over the trestles, so as to approximately level the platform. This platform was composed of rails, greased on the surface, and the girders were easily hauled over it until the ends rested on the abutment and pier, after which they were put into position by the derricks as before.

The trestles were held in position by the rails laid over them, the only difficulty being to choose the moment for launching the girders; and this was the cause of some anxiety. Floods frequently interrupted the work, and the trestles sank unequally in the bed, and had to be repacked many times. They were also twice washed away, but as they were all chained together and the first one was securely attached to the track, they were easily recovered when the flood receded, together with the sleepers for packing and the platform rails. The floods were sudden, the water rising rapidly 9 feet or 10 feet when storms occurred on the hills. When the main girders of the first span were erected, the cross-girders were inserted, and greased rails were laid over them. Over these and the trestles, which had been transferred from the first to the second span, the girders of the second span were hauled.

Another bridge of five spans, over the Pueblo Viejo River, was erected by a sub-contractor, who preferred to excavate the foundations without pumps, and erect the girders *in sitú*, being in possession of piles, timbering, pile-drivers, excavators, etc. The work was finished satisfactorily, but slowly.

Cost of Ironwork.—The following prices were paid for the ironwork, all plant and tools being supplied, and the transport effected, by the Company:—

	£	s.	d.	
Sorting material in yard	0	2	6	per ton.
Riveting main girders	2	10	3	„ „
Loading on wagons and erecting main girders	1	17	8	„ „
Completing spans	4	7	11	„ „

the total for erection being £242 12*s.* per span, or about £4 10*s.* per ton.

The Chief Engineer of the railway is Mr. E. H. Woods, M. Inst. C.E., who placed the design of the bridges in the hands of the Author, and eventually appointed him Resident Engineer for the survey and construction of the line.

The Paper is accompanied by a sheet of tracings, from which the *Figs.* in the text have been prepared.

(Paper No. 2914.)

"A New Method for Determining the Supporting Power of Piles."

By FRANZ KREUTER, Professor of Civil Engineering in the Royal Technical High School of Munich.

IT is often impossible to test bearing-piles by the direct application of a sufficient load, and the supporting power can then be ascertained only by means of certain formulas, either rational or empirical. The most noticeable among the former are those of Redtenbacher and of Rankine. All the formulas hitherto proposed, however, are defective, and this deficiency is chiefly due to the following uncertainties :—

(1) The blow or concussion between the hammer and the pile is usually, for safety, supposed to be inelastic; but this is obviously not the case. The allowance, however, which should be made for the elasticity of the blow is unknown.

(2) It is not certain whether, as being compressed by the action of the blow, a length equal to the whole actual length of the pile or to some part of it only should be introduced. Redtenbacher in his formula inserts the whole, Rankine only one-half of the real length of pile.

(3) The weight of the timber of which the pile consists, and which is introduced into Redtenbacher's formula, varies for pine between 30 lbs. and 44 lbs. per cubic foot.

(4) The modulus of elasticity of pine may vary between 1,400,000 lbs. and 1,800,000 lbs. per square inch.

These formulas in consequence differ widely in their results. Other formulas in which the compressibility of the timber is neglected are to be condemned as being apt to lead to serious errors in all cases, unless the influence of the elasticity of the timber is inappreciable. This only occurs when a comparatively light pile is driven into soft ground by heavy blows. The empirical formulas are in most cases merely based upon conjecture rather than upon reliable observation, for the reason that the real supporting power of bearing-piles cannot always be tested by the

application of a sufficiently large dead-load. On the most favourable assumption they will be approximately correct only for cases similar to the one from which they have been deduced, and their generalization will always be open to suspicion. They are therefore still less trustworthy than rational formulas.

The Author proposes to show a new method, at once simple and reliable. The supporting power is generally required only when the pile has been already driven into the ground to a considerable depth, and sinks comparatively very little further after a certain number of subsequent blows or sets of blows. It may in that case be concluded that when the penetration of the pile after a blow has become very small in comparison to the total depth already attained, the increase of supporting power will be also small in comparison with the total supporting power it already possesses.

Now let W be the weight of the hammer and h the height from which it falls, then—

$$E = W h \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

gives the energy of the blow or set of blows, as the case may be. This energy is spent in producing a number of different effects, which, however, may be summed up in two classes, one of which represents the useful work, whilst the other comprises all that work which is of no use for the particular purpose, and which may therefore be regarded as lost. Let the former be expressed by U and the latter by V, then it is evident that—

$$E = U + V.$$

U only represents the work done in driving the pile against the resistance of the ground through a measurable distance or depth d; and this resistance of the ground to the penetration of the pile is the bearing power of the latter, L; therefore—

$$E = L d + V \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The hammer only does useful work from the moment when the pile begins to move, or as soon as—

$$d > 0.$$

As long as d remains zero all the work done by the hammer is useless or lost. Let E_o be the energy necessary to balance the loss V at the limit when the pile will just begin to penetrate further; then—

$$V = E_o$$

If now the value E_o be found, beyond which the loss V cannot

increase—because for any value of $E > E_o$ the resistance of the ground is overcome and the pile will penetrate—it follows directly from (2) that—

$$L = \frac{E - E_o}{d} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It is true that E_o cannot be determined in a direct manner; but it may be deduced with sufficient accuracy from the result of two subsequent blows, or sets of blows, in the following manner: Make two consecutive and efficient sets of an equal number of blows, but of different energies, E_1, E_2; that is to say, in using the same hammer apply different heights, h_1, h_2. If the pile still advances considerably let the blows of the second set be the weaker; if the advance of the pile is small let the second set of blows be the heavier. Let d_1, d_2 be the depths through which the pile is driven by the action of the energies E_1, E_2 respectively; then, subject to the condition that d_1 as well as d_2 be sufficiently small in comparison with the whole depth already attained, it may be assumed that L as well as V will remain sensibly constant in passing from the first set of blows to the second, so that from (2) it may be deduced—

$$\frac{d\,(E)}{d\,(d)} = \text{constant, nearly.}$$

The law according to which E and d vary together may therefore in this case, and within the limits in question, be approximately represented by a straight line, inclined towards the rectangular axes of co-ordinates and intersecting one of them in the point corresponding to—

$$d = 0,\ E = E_o;$$

so that

$$\frac{E_1 - E_o}{E_2 - E_o} = \frac{d_1}{d_2},$$

whence

$$E_o = \frac{E_2 d_1 - E_1 d_2}{d_1 - d_2} \text{ nearly} \quad . \quad . \quad . \quad (4)$$

If now in (3) and (4) the number of blows used in the testing set be cancelled, the equations may take the form—

$$L = \frac{h - h_o}{D} \cdot W \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

$$h_o = \frac{h_2 D_1 - h_1 D_2}{D_1 - D_2} \quad . \quad . \quad . \quad . \quad (4a)$$

where D is the average depth through which the pile is driven by one blow of the respective set of blows.

Since, for h and D in (3*a*), h, or h_2 and D_1 or D_2 respectively, may be substituted, the bearing power of pile may be finally expressed:—

$$L = \frac{h_1 - h_2}{D_1 - D_2} \cdot W \quad . \quad . \quad . \quad . \quad . \quad (5)$$

This method is more reliable than any other, dispensing, as it does, with all uncertain assumption and being merely founded upon observations in connection with the special case in question.

Preparatory to ascertaining the supporting power of piles by the method explained the following precautions are of great importance:—

(1) The piles should rest for some time in order to allow the stresses produced in the ground by the penetration of the piles to be relieved. It has been stated from experience that piles frequently penetrate with renewed ease after some days' rest. An immediate test-driving might therefore lead to erroneous results and to too high an estimate of the supporting power of the piles.

(2) The heads of the test-piles should be sawn off to present a sound and solid surface to the blows of the hammer.

(3) The number and force of the testing-set of blows should be such as not to crush the head of the pile.

ADDENDUM.

The Author has been able to examine the practicability of the new formula by comparing it with the results of experiments. The formula appears to give quite satisfactory values when the conditions under which it is applied are well maintained.

The results of two sets of blows, $W h_1 = L_1 D_1 + V_1$ and $W h_2 = L_2 D_2 + V_2$, can only give the expression $\frac{L}{W} = \frac{h_1 - h_2}{D_1 - D_2}$, when L_1 is assumed to be equal to L_2 and the difference between V_1 and V_2 can be neglected. The latter, however, is not always the case, and the loss of work must certainly increase with the energy of the blows.

The object of the proposed two testing-sets of blows is merely to enable the value E_c, or the height h_o, to be determined, beyond

which the work ceases to be entirely lost. The hypothesis upon which all the further conclusions are based are:—that the losses of work in the testing-sets of blows remain sensibly the same as in the set E_o; and that the curve showing the law according to which E and d vary together be straight to a certain distance from its zero. Hence it follows that, in order to obtain reasonable results from the formula (5), the heights h_1 and h_2 from which the hammer shall fall in the testing-sets of blows must not be too widely different, and must be as close as possible to h_o. Great values of h_1 and h_2, under the influence of which the pile still advances considerably, can therefore not be used in the experiment, even if the difference between h_1 and h_2 is comparatively small.

(*Paper No. 2937.*)

"The Chicago Conference on Aerial Navigation."

By Dr. W. Pole, F.R.S., M. Inst. C.E., Honorary Secretary.

Among the many curious novelties presented to the world at the great Chicago Exhibition of 1893, was an "International Conference on Aerial Navigation," and its occurrence marks a modern step in engineering science.

The question "whether man, the creature of the earth, can ever attain to the empire of the air, as he has already attained to the empire of the sea," is one of the oldest that has interested civilized society; but it is only within the last few years that it has been considered worthy of scientific study. The attempts, early begun and long continued, at imitating the birds were always found to be failures; and, though the invention of the balloon appeared to make the problem easier, yet the main object, namely, motion in a voluntarily controlled direction, seemed as far off as ever. Indeed, the idea was, not unfrequently, pronounced to be a physical impossibility. But Lavoisier had pointed out on what principles a balloon might be guided; and, some quarter of a century ago, attempts were made to carry these principles into practice. The Author of this Paper believes he was the first person to describe these attempts to English readers, and to predict, in reasonings and calculations laid before this Institution, that they contained the promise of what might, before long, prove to be a practical means of aerial locomotion.[1]

Further trials verified his predictions, and now voluntary locomotion through the air is admitted as a fit subject for engineering study, like that on the land or on the water. There had been some kind of meeting on the subject at Paris in 1889, when the Government war-balloon was exhibited, and this gave the idea that the subject was being studied in various

[1] "Quarterly Review," July 1875; "Fortnightly Review," Jan. 1881; Minutes of Proceedings Inst. C.E., vol. lxvii., Session 1881–82, page 369, and vol. lxxxi., Session 1884–85, page 233.

parts of Europe; but the Chicago Conference was much more pretentious, and it may be interesting to give some idea of what was done there. The following particulars are extracted from a large and closely printed volume of the Proceedings.[1]

The Conference lasted four days, and its proceedings were directed by a committee of

The World's Congress, Auxiliary of the World's Columbian Exposition of 1893: Department of Engineering.

The objects were: to bring about the discussion of some of the scientific problems involved; to collate the results of the latest researches; to procure an interchange of ideas; and to promote concert of action among the students of this inchoate subject.

The general arrangement was to include three main topics.

I. Scientific Principles: such as the properties of the air; propellers and motors; materials of construction; and general structural forms.

II. Aviation: meaning the discussion and imitation of the flight of birds; and the subject of flying machines generally.

III. Ballooning: the construction and principles of action of balloons; and their probable improvement.

The Conference was opened by an address from Mr. O. Chanute, Civil Engineer, of Chicago, who had published a lecture on the subject given in Cornell University in 1890.[2] He gave a lucid account of the state of knowledge on the subject generally, after which many Papers were read and discussed. Thirty-eight are printed, wholly or partially, in the volume above mentioned, following no order of subjects; but it will be more convenient here to notice the most prominent matter they contain on the three heads of division above given.

I. General Scientific Principles.

The first Paper published is a long and elaborate one by a young engineer, Mr. C. W. Hastings of Chicago, who unhappily died before the date of the Conference. Without describing any particular apparatus, the author investigates the general subjects of

[1] Proceedings of the International Conference on Aerial Navigation, held in Chicago, August 1, 2, 3 and 4, 1893. Published by the American Engineer and Railroad Journal, New York, 1894.

[2] Neither Mr. Chanute nor anyone else who took part in the Conference appears to have been aware of any of the previous publications on the subject in this country.—W. P.

balloon flight, and of mechanical flight, dividing the latter into the two branches of orthogonal or "beating" flight, and of gliding or "sailing" flight, and noticing the supporting surface, its outline, character and shape, and the stability of the structure. He then goes into the discussion of the power required, the motive instrument, particularly the screw propeller, and then the varieties of modes of producing and applying the motive power. All these matters are elaborately discussed, with mathematical treatment when necessary, and the Paper on the whole is an extremely interesting one.

The next Paper is also a long one, remarkably original, by Professor S. P. Langley, who was previously well known in regard to the subject by his striking "Experiments in Aerodynamics" in 1891, which threw a new light on the motion of certain forms of bodies through the atmosphere, and offered much encouragement to the further study of dynamic flight.[1]

Professor Langley's Conference Paper is entitled "The Internal Work of the Wind;" the following extract will show its object. He says:—

"It has long been observed that certain species of birds maintain themselves indefinitely in the air by *soaring*, without any flapping of the wing or any motion other than a slight rocking of the body; and this, although the body in question is many hundred times denser than the air in which it seems to float, with an undulating movement, as on the wave of an invisible stream.

"No satisfactory mechanical explanation of this anomaly has been given, and none would be offered in this connection by the writer were he not satisfied that it involves much more than an ornithological problem, and that it points to novel conclusions of mechanical and utilitarian importance. They are paradoxical at first sight, since they imply that, under certain specified conditions, very heavy bodies, entirely detached from the earth, immersed in and free to move in the air, can be sustained there indefinitely without any expenditure of energy from within." . . .

"The writer, like others, has satisfied himself by repeated observations, that the soaring vultures and other birds appear as if sustained by some invisible support in the stream of air, sometimes for at least a considerable fraction of an hour." . . .

"This, it might seem, is, without misuse of language, to be called a physical miracle."

The author cites the work of L. P. Mouillard "L'Empire de l'Air" in support of these facts; and he then states at some length how he was led to conjecture where the explanation of them might be looked for, and to design special apparatus to test his conjectures. The observations thus made showed—

"That 'wind' in general was not what it is commonly assumed to be, *i.e.*, air

[1] Minutes of Proceedings Inst. C.E., vol. cvii., Session 1891-92, p. 546.

put in motion with an approximately uniform velocity in the same strata, but that, considered in the narrowest practicable sections, wind was always not only not approximately uniform, but variable and irregular in its movements beyond anything which had been anticipated, so that it seemed probable that the very smallest part observable could not be treated as approximately homogeneous, but that even here there was an internal motion to be considered, distinct both from that of the whole body and from its immediate surroundings. It seemed to the writer to follow as a necessary consequence that there might be a potentiality of what may be called 'internal work' in the wind. On further study it seemed to him that this internal work might conceivably be so utilized as to furnish a power which should not only keep an inert body from falling, but cause it to rise."

The author gives particulars, with diagrams, of many observations on the wind, showing evidence of its complex nature, of its internal movements, and of the resulting potentiality of its internal work; with special reference to their important bearing on the science of *aerodronomics* (from ἀεροδρομέω, to traverse the air). One prominent feature was, that the higher the absolute velocity of the wind the greater the relative fluctuations which occur in it. In a high wind the air moves in a tumultuous mass, the velocity being at one moment perhaps 40 miles an hour, then diminishing to an almost instantaneous calm, and then resuming.

The author does not enter on any inquiry as to the cause of these phenomena, but he considers that, admitting that the wind is very elastic and frictionless, the incessant alterations are due to past impulses and changes which are preserved in it, and which die away with very considerable slowness. He then points out examples of how these internal variations may be utilized by the birds to produce such phenomena as those which dictated the enquiry.

He sums up the leading points of his memoir essentially thus:—

1. The wind is not even an approximate uniform moving mass of air, but consists of a succession of very brief pulsations of varying amplitude, and, relatively to the mean movement of the wind, these are of varying direction.

2. Hence there is a potentiality of "internal work" in the wind, and probably of a very great amount.

3 and 4. An inclined surface may thereby be sustained, or even raised, or made to advance against the wind without expenditure of internal energy.

5. This is not only mechanically possible, but is realisable in practice.

Prof. Langley's Paper was discussed at some length by many

eminent authorities, and his idea was practically supported by a Paper on "Atmospheric Gusts," by A. F. Zahm.

The irregularity of the structure, if one may use the expression, of high winds had heretofore attracted the notice of observers, though in an imperfect way. In 1873, the Author of this Paper was engaged with Mr. W. H. Barlow on the investigation of a large design for a bridge across the Forth, by Sir Thomas Bouch, and as the wind-pressure was a very important point, it was determined to apply to the Astronomer Royal, Sir George Airy, for information thereon. He kindly replied to the inquiries, and, as his letter was subsequently published,[1] there is no impropriety in giving the following extracts referring to the wind's action. The letter is addressed to Mr. Barlow, and dated 9th April, 1873.

"We know that upon very limited surfaces and for very limited times, the pressure of the wind does amount sometimes to 40 lbs. per square foot, or in Scotland probably to more. So far as I am aware, our positive knowledge, as derived from instrumental record, goes no further. But in studying the registers it is impossible not to see that those high pressures are momentary, and it seems most probable that they arise from some irregular whirlings of the air which extend to no great distance; I should say, certainly to no distance comparable with the dimensions of the proposed bridge; and that the fairest estimate of the pressures on the entire bridge would be found by taking the mean of the recorded pressures at one point of space for a moderate extent of time, as representing the mean pressure upon a moderate extent of space at one instant of time. Adopting this consideration, I think we may say that the greatest wind-pressure to which a plane surface like that of the bridge will be subjected on its whole extent, is 10 lbs. per square foot."

Now here the venerable Astronomer Royal has clearly indicated, as the results of his official observations, two things in regard to the wind-force and the wind-motion. First, that a certain maximum pressure, at a given point, exists only for a "very limited time;" *i.e.*, that the particular stream of air impinging on that point is subject to great fluctuation of force or pressure, which seems to be an idea similar to that expressed by Professor Langley. Then Sir George adds another item of knowledge, namely, that that maximum pressure extends only over a "very limited surface," *i.e*, that the whole current must be considered as divided up longitudinally into a number of small parallel streams, each of which has or may have a different force, or rather a different arrangement of forces from those immediately around it. To these may be added a third irregularity, which any one may see by

[1] Report of the Court of Inquiry and Report of Mr. Rothery, upon the circumstances attending the fall of a portion of the Tay Bridge on the 28th December, 1879. Parliamentary Paper, 1880 [C—2,616].

watching a vane in a high wind, namely, that the stream impinging on any point is constantly varying in direction, causing the vane to oscillate rapidly.

During the subsequent erection of the Forth Bridge, from 1882 onwards, a series of elaborate experiments was made at its site, by Sir John Fowler and Sir Benjamin Baker, on the action of the wind.[1] They referred in a great measure to the effect produced by it on the peculiar structure of the members of the bridge, and this portion of the investigation, though exceedingly interesting and instructive, need not be further dwelt on here. But the chief results illustrating the nature of the wind itself may be stated as follows:—There were three wind gauges or pressure boards; a large one, 300 square feet in area, and two small ones each of $1\frac{1}{2}$ square foot area. Sir Benjamin had anticipated that, contrary to the opinion of many, the large board would show a smaller average pressure per square foot than the small ones, and the results bore out fairly his anticipations, the effective pressure on the large and heavy board averaging only about two-thirds of that indicated by an ordinary light anemometer. Two very heavy gales were experienced in the winter of 1883–4, and during one of them the small gauge was reported as registering 65 lbs. per square foot, but this was found to be due largely to instrumental defects, and by the large board it was shown as only 35 lbs. Sir Benjamin makes the following remarks on the subject:—

"I look upon the record of 65 lbs. therefore as valueless so far as regards the specific maximum pressure attained during the great storm, but of considerable value as evidence that the highest pressure, whatever it might have been, partook of the character of a smart jerk of too instantaneous duration to affect a structure of any size or weight. From the records generally, and from my own watching of the movements of the three gauges, I have come to the conclusion that uniform velocity and pressure in a wind, whether it may prevail or not at cloud-heights, can never obtain near the surface of the earth or in the neighbourhood of any bridge or other structure capable of causing eddies. Unsteady motion must be the rule in air as in water, and the threads of the currents moving at the highest velocity will strike an obstruction successively rather than simultaneously, so that the mean pressure per square foot on a large area must be less than that on a small surface from that cause alone, irrespective of possible differences in the partial vacuum at the back of the planes."

Sir Benjamin confirmed this opinion, by ingenious observations and calculations on the angle at which a sailing vessel heeled over during a strong broadside gale; the vessel kept steadily showing a mean pressure of 12 lbs. only per square foot, while heavy local

[1] "The Forth Bridge," by Sir Benjamin Baker, read at the Montreal meeting of the British Association, 1884; Library Inst. C.E., Tracts 4to. Vol. 93, No. 4.

gusts of very small area struck different parts of her in a distinctly recognisable manner.

These observations, therefore, seem in some measure to anticipate the conclusion of Professor Langley, that in a high wind the air moves in a tumultuous and irregular mass, and that the higher the general velocity the more violent are the fluctuations. But, of course, his explanation of the peculiar nature and import of these fluctuations, as showing "internal work," is entirely original.

To return to the Papers laid before the Conference. Another general subject of great importance is that of *motive power*. This applies to all classes of aerial machines, and has, therefore, always had much attention; the aim being to combine the maximum of efficiency with the minimum of weight. The imitation of the ornithological motive apparatus has never been successful, and it has only been in late years that the invention of the screw propeller, and the modern skill in mechanical construction, have brought aerial navigation within the reach of practical engineering science.

The earliest promising efforts were made in Mr. Giffard's balloon of 1852 with a steam-engine and a screw. Mr. Dupuy de Lôme, in 1872, used the power of men, with a great waste of weight. In 1881 the lightest efficient motor the Author could hear of, was a steam-engine made by Mr. Thornycroft, weighing about 40 lbs. per horse-power, but great improvements have been made since that time. Mr. Chanute mentions an announcement by Mr. Maxim that "he has constructed two steam-engines of 300 HP. which, with the engine proper, the boilers, pumps, generators, condensers and the weight of water in the complete circulation, weigh but 8 lbs. to the horse-power." And that, whereas the coefficient of efficiency in the earlier aerial screws was less than 35 per cent., the same experiments had increased it to at least double.

Mr. Hastings devotes much attention to the theoretical action of the aerial screw, showing it to be a very effectual and manageable device. In regard to the motive power, he considers that a heavier one than 15 lbs. per HP., including all that pertains to it, will not answer. Gas-engines he believes unsuitable, but he thinks that explosive-engines of some other kind may be applicable. At the same time, the steam-engine has great advantages and may probably be made light enough to be efficient, and the best fuel for it may probably be found to be oil. The water should be condensed, as proposed by the Author of this Paper in 1881. Mr. Hastings thinks a kind of "steam-turbine" may prove the lightest

of motors, and this forms the subject of a special Paper by Mr. Dow.

Mr. Hastings alludes to the use of electric-motors, as used in France, and thinks that in the present state of knowledge they would be the easiest of all to develop to the required point of lightness.

Mr. H. C. Vogt, naval engineer of Copenhagen, contributes an article on "Air-Propellers," which might, he considers, be applied, not only to navigate the air but to the propulsion of boats on the water.

Mr. Kress also recommends a peculiar kind of "elastic air-screw."

Among the other Papers on this branch of the subject is an excellent one on "Anemometry," by S. P. Fergusson, of Blue Hill Observatory.

An elaborate set of notes on the "Materials of Aeronautic Engineering," by Robert H. Thurston, particularly aims at the attainment of strength with light weight.

II. Aviation.

This division refers to the imitation of bird flight by machines heavier than the air, which have not only to propel themselves but to overcome the force of gravity, and it appears to have been specially encouraged at the Conference. Mr. Chanute, in his opening address, says, "As to flying machines proper, which promise high speeds, we can say that the elements of an eventual success have gradually accumulated during the past half century. The argument which has been made that man cannot hope to float his greater weight upon the air would seem not to be well founded. There has been real substantial advance within the last few years." Mr. Hastings, his pupil, has discussed at much length the theoretical views affecting the various aspects of the problem.

Elaborate observations are given in several Papers respecting the sailing and soaring flight of birds, on which the ideas of those supporting aviation are modelled. There is also a general Paper on "Flying Devices," and many notes are contributed on the design of flying machines. But so far as this Conference is concerned, although, thanks chiefly to Professor Langley, there has been considerable advance in the general knowledge of the principles connected with movements through the air, and although mention is occasionally made of considerable mechanical improvements in the general modes of obtaining light motive-power, there appears no account of any complete solution of the problem.

III. Ballooning.

This alternative form of aerial navigation has at least the advantage over mechanical flight, that it has been already put in successful practice. But it is objected to as introducing an element considered undignified and unworthy, namely, the evasion of the difficulty of gravity by the flotation. The "gas-bag," as it is termed, is viewed as having no precedent in the ornithological apparatus on which, it is argued, aerial locomotion should be modelled.

Yet it requires but a little consideration to show how unfounded, and indeed how unreasonable, such an objection is. The aim is for man to acquire the empire of the world of air, as he has acquired the empire of the ocean. But how has he acquired the latter? Not by imitating the fishes, but by introducing the identical new and foreign element of artificial flotation by displacement of the fluid to be commanded. The boat on the water corresponds with the "gas-bag" in the air, and there is no more sense in despising the latter, than there would be in arguing for the abolition of boats, and the substitution of ingeniously-contrived swimming machines! The boat is a legitimate result of the intellect of man in circumventing natural obstacles, and so is the balloon.

Ballooning was not strongly encouraged at the Chicago Conference. Mr. Chanute mentions fairly enough the successful trials in France, and their proposed extensions, with an expectation of attaining a speed of about 25 miles an hour, which he saw no reason to doubt; but he adds—

"The attainment of this moderate speed requires very large and therefore very costly balloons, which carry very few passengers, and it is clear that while such craft may be justified by the exigencies of war, they cannot compete commercially with existing modes of transportation. . . . It is difficult to conceive how, if they be made of sufficient size, . . . such enormous and frail craft can be handled, housed, or operated, without peril of casualty or disaster."

He then alludes to the discoveries of Prof. Langley, which, he conceives, favour the alternative plan of mechanical flight, "a mode of transportation which so strongly appeals to the imagination."

Mr. Hastings follows in the same strain. After stating the results of the French experiments, and adding that only one of the four balloons started had been able to return to its starting-point, and that none of them was ever tried but once, he says—

"These facts are rather discouraging to those who hope to achieve aerial

navigation through the means of a navigable balloon. If the French Government, by the use of more money than the most enthusiastic company of promoters could hope to secure, and with presumably the best ability that it was possible to obtain; . . . if the French Government, with these advantages, and with several years of diligent trial, was unable to achieve more than the very moderate success stated, it would seem as if it were useless for others to attempt to solve the problem in this way, and without Government aid."

He then explains the well-known relations between power and velocity, which, as with steam-ships, require increase of size for larger cargoes and greater speeds, and he argues that the smaller results of which the smaller machines are capable would make them commercial failures. He concludes thus—

"It is evident, that if the navigable balloon is to be kept in 'commission' as many hours in the day and as many days in the year as is the steamboat or locomotive, the cost of maintenance will be ruinous. The income from a navigable balloon must therefore be very considerable in order to meet its maintenance. The character of the material of which it is constructed is so fragile that the apparatus is extremely liable to accident; and, as compared with wood or iron, it is very short lived. Those capitalists, therefore, who may venture their money in a navigable balloon project, should calculate on large rates of profit to compensate them for the risks of the business, and in any case should expect to get their money back in a very few months or not at all."

Mr. Chanute was more favourable to the balloon in his lecture of 1890, when he described the past proceedings of the French engineers, and discussed their views for the future. He pointed out difficulties, but added—

"These difficulties can all be surmounted, no doubt, including the remaining one, that large balloons will be costly, and that few can afford to experiment with them."

And he summed up with the remark—

"It seems likely, therefore, that in the near future elongated balloons will be built, which will be driven at 25 or 30 or a few more miles per hour, which will be able to sail about on all but stormy days; but the cargoes carried in proportion to the size will be small, and to obtain speeds similar to those of express trains some other form of apparatus will have to be sought for."

In comparing the balloon speed with that of express trains, Mr. Chanute omitted to notice that when the balloon is fortunate enough to go with the wind, its speed with regard to the earth may be very considerable.

After describing the rival plan of mechanical flight, Mr. Chanute, at the conclusion of the lecture, said—

"Success with aeroplanes, if it comes at all, is likely to be promoted by the navigable balloon. It now seems not improbable that the course of development will consist, first in improvements of the balloon, so as to enable it to stem the winds most usually prevailing, and then in using it to obtain the initial

velocities required to float aeroplanes. Once the stability of the latter is well demonstrated, perhaps the gas-bag can be dispensed with altogether."

According to these views, one would think that more encouragement might have been offered to balloon improvement at the Conference. It seems to be admitted by all competent judges that, in the "gas-bag" contrivance, as now made successfully "dirigible" at speeds greater than ordinary winds, the empire of the air has been essentially acquired. How it may be improved? what uses can be made of it? and what dividend it may be made to yield to commercial people who embark capital in it? are questions the answers to which must wait for further development, as has been the case with all new inventions. Meanwhile, there may be repeated the closing words of the first English account of modern aerial navigation, written twenty years ago, "At all events a dirigible balloon is a thing actually in existence; a flying machine is, at present, only an idea."

The other communications on this subject are as follows:—

Mr. Myers describes his mode of manufacture of balloons for hydrogen gas, and the effects of temperature in balloon voyages; giving also some experiments tried by him on different forms of balloons and methods of manœuvring.

Mr. Wood makes some comparison between "flotation" and "aviation," giving preference to the former.

Several communications refer to the use of the ordinary balloon for explorations of the upper atmosphere and for general meteorology. One of these is by a well-known authority, Mr. de Fonvielle, and is of considerable value.

On the whole, it would hardly seem that any result of importance has followed the Conference, except the publication of Professor Langley's new theory of the internal work of the wind, which may perhaps prove of utility hereafter. The meeting has, however, contributed to spread the knowledge of what has been done, and may tend, therefore, to convince the public that the idea of aerial navigation is not a delusion, but is worth serious study.

The Institution of Civil Engineers has not hesitated to circulate this opinion, as may be judged from the following passage in the opening address of the President,[1] Mr. W. H. Barlow, on the 13th January, 1885:—

"There may undoubtedly be particular circumstances in which it [locomotion by dirigible balloons] would be useful, such, for example, as the

[1] Minutes of Proceedings Inst. C.E., vol. lxxx., Session 1884–85, p. 27.

exploration of new countries, or as the present Egyptian campaign. I strongly suspect that if our lively neighbours, instead of ourselves, had been invading the Soudan, they would long before this have had a 'dirigible' balloon looking down into Khartoum."

It may be mentioned that several societies are now formed for the purpose of studying aerial navigation, among which are the British Aeronautical Society; the Aerial Navigation Society of France; the Aviation Society of Munich; the Imperial Aeronautical Society of Russia, and the Aviation Society of Vienna. There is also a magazine published every other month in Berlin (now in its fifteenth year), entitled, *Zeitschrift für Luftschiffahrt und Physik der Atmosphäre.*[1]

[1] This periodical is in the Library of the Inst. C.E.

(Paper No. 2968.)

"The Problem of the Connecting-Rod."

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The problem of the connecting-rod, on the assumption of uniform velocity for the crank-pin, has hitherto been solved approximately only.[1] A graphical solution has also been given.[2] In all practical cases, considerable changes may be made in the length of the connecting-rod, without making much change in the maximum velocity of the piston. Hence if a graphical solution is to be of value the drawing must be extremely accurate. It seems desirable therefore to give a solution of the problem which will give the maximum velocity of the piston in any case, depending only on the use of certain rules.

The points of interest in the problem are the determination of

(A) The maximum velocity of the piston.

(B) The position of the crank when the piston is moving with its maximum velocity.

(C) The effect of a change in the length of the connecting-rod on the maximum velocity of the piston, and on the position of the crank when the piston has its maximum velocity.

The solution of the problem is as follows:—

Let r be the ratio of the length of the connecting-rod to the length of the crank; S the ratio of the maximum velocity of the piston to the velocity of the crank-pin; and let an angle α be determined which satisfies the equation

$$\cos 3\alpha = \frac{27}{16\,r^2} - \frac{11}{16}.$$

If $\alpha = \alpha_0$ be one solution, then $\alpha = \alpha_0 + 120°$ and $\alpha = \alpha_0 + 240°$ are also solutions.

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[1] "Applied Mechanics," by J. H. Cotterill. London, 1892, p. 102.

[2] "The Mechanics of Machinery," by A. B. W. Kennedy. London, 1886, pp. 102–115.

One of these three solutions, and one only, will be found to give the value of an acute angle β satifying the equation

$$\cos 2\beta = \frac{8}{3} r^2 \cos \alpha - \frac{2}{3} r^2 + 1.$$

This value of β is the angle between the crank and the line of motion of the piston, when the piston velocity is greatest; and then, if, as in all practical cases,

$$r > 1{\cdot}265 \left[= \frac{1}{5}\sqrt{40} \right],$$

$$S = \frac{1}{2}\left(3 \sin \beta - \sqrt{\frac{5}{2} \cos (180^\circ - 2\beta) - \frac{3}{2}}\right).$$

But if $$1 < r < 1{\cdot}265,$$

then $$S = \frac{1}{2}\left(3 \sin \beta + \sqrt{\frac{5}{2} \cos (180^\circ - 2\beta) - \frac{3}{2}}\right).$$

It is also shown that as r increases from 1 to 1·265, β decreases from 90° to 63° 26′ 5·8″, which is the angle whose tangent is 2, and S decreases from 2 to 1·342 $\left[= \frac{3\sqrt{5}}{5} \right]$.

As r further increases from 1·265 to an infinitely great value, β increases from 63° 26′ 5·8″ to 90°, and S decreases from 1·342 to 1.

In all practical cases r lies between 3 and 5. It will be found that

when $r = 3$, S = 1·055, $\beta = 73^\circ\ 10'\ 31''$;
when $r = 4$, S = 1·031, $\beta = 76^\circ\ 43'\ 17''$;
when $r = 5$, S = 1·019, $\beta = 79^\circ\ 5'\ 58''$.

Velocity of the Piston.—If O x, *Fig. 1*, is the line in which the piston-head Q moves, P be the crank-pin, O P = a, and P Q = $r\,a$, so that r is greater than unity, O P revolving with uniform angular velocity ω,

$$O\,Q = a\,(\cos\theta + r \cos\phi),$$

and $$-\frac{d\,(O\,Q)}{d\,t} = a\left(\sin\theta \frac{d\,\theta}{d\,t} + r \sin\phi \frac{d\,\phi}{d\,t}\right);$$

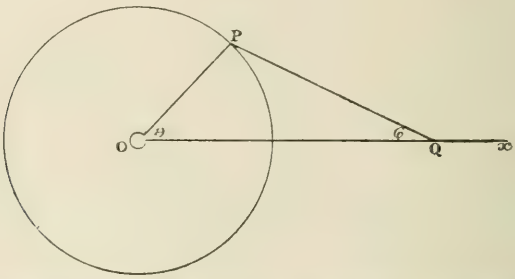
but $$\frac{d\,\theta}{d\,t} = \omega, \text{ and } a \sin\theta = r\,a \sin\phi,$$

$\therefore$ $$\cos\theta \cdot \omega = r \cos\phi \frac{d\,\phi}{d\,t},$$

$\therefore$ $$-\frac{d\,(O\,Q)}{d\,t} = a\frac{d\,\theta}{d\,t}\left(\sin\theta + \sin\phi \frac{\cos\theta}{\cos\phi}\right).$$

Now $a\,\frac{d\,\theta}{d\,t}$ is the velocity of the crank-pin, and $-\,\frac{d\,(\mathrm{O\,Q})}{d\,t}$ is the velocity of the piston towards O.

Fig. 1.



Maximum Velocity of the Piston and position of the Crank corresponding with it.—The ratio s, between the velocities of the piston and the crank-pin, is equal to

$$\sin\theta + \cos\theta\tan\phi, \text{ or } \sin\theta + \frac{\sin\theta\cos\theta}{\sqrt{(r^2-\sin^2\theta)}},$$

and $$\frac{d\,s}{d\,\theta} = \cos\theta + \frac{\cos^4\theta + 2\cos^2\theta\,(r^2-1) - r^2 + 1}{(r^2-\sin^2\theta)^{\frac{3}{2}}}.$$

Now $$\cos^4\theta + 2\cos^2\theta\,(r^2-1) - r^2 + 1$$
$$= (\cos^2\theta + r^2 - 1 + r\sqrt{r^2-1})\,(\cos^2\theta - \sqrt{r^2-1}\,(r - \sqrt{r^2-1})),$$

and $$\sqrt{r^2-1}\,(r - \sqrt{r^2-1}) = \frac{\sqrt{r^2-1}}{r + \sqrt{r^2-1}} < 1.$$

Hence an acute angle α exists such that

$$\cos^2\alpha = \sqrt{r^2-1}\,(r - \sqrt{r^2-1}),$$

$\therefore$ $$\cos^4\theta + 2\cos^2\theta\,(r^2-1) - r^2 + 1$$
$$= (\cos^2\theta + r^2 - 1 + r\sqrt{r^2-1})\,(\cos^2\theta - \cos^2\alpha).$$

Since in the mechanical problem r is greater than 1, the factor $\cos^2\theta + r^2 - 1 + r\sqrt{r^2-1}$ is greater than 0, the factor $\cos^2\theta - \cos^2\alpha$ is positive between $\theta = 0$ and $\theta = \alpha$, and between $\theta = \pi - \alpha$ and π; but negative from $\theta = \alpha$ to $\theta = \pi - \alpha$.

Now $$\frac{d\,s}{d\,\theta} = \cos\theta + \frac{(\cos^2\theta + r^2 - 1 + r\sqrt{r^2-1})\,(\cos^2\theta - \cos^2\alpha)}{(r^2-\sin^2\theta)^{\frac{3}{2}}},$$

hence $\frac{d\,s}{d\,\theta}$ is the sum of two terms, the first of which, $\cos\theta$,

changes sign when $\theta = \frac{\pi}{2}$; and the other when $\theta = \alpha$ and $\theta = \pi - \alpha$.

It is necessary to determine the sign of $\frac{ds}{d\theta}$ for all values of θ between 0 and π.

(1) In the interval between $\theta = 0$ and $\theta = \alpha$, both terms are positive, therefore $\frac{ds}{d\theta} > 0$.

(2) In the interval between $\theta = \alpha$ and $\theta = \frac{\pi}{2}$, $\cos\theta > 0$; the other term is negative, hence $\frac{ds}{d\theta} \gtreqless 0$, according as

$$\cos\theta \gtreqless \frac{(r^2 - 1 + r\sqrt{r^2-1} + \cos^2\theta)(-r^2 + 1 + r\sqrt{r^2-1} - \cos^2\theta)}{(r^2 - \sin^2\theta)^{\frac{3}{2}}}.$$

Both sides of the above inequality are now positive. Hence they may be squared, and multiplied by the positive quantity $(r^2 - \sin^3\theta)^3$, and then the inequality becomes

$$\cos^2\theta\,(r^2 - \sin^2\theta)^3 \gtreqless \left[r^2(r^2-1) - (r^2 - 1 + \cos^2\theta)^2\right]^2,$$

or $$0 \gtreqless (r^2 - 1)\left[\cos^6\theta + (r^2 - 3)\cos^4\theta - (r^2 - 1)(r^2 + 3)\cos^2\theta + (r^2 - 1)\right].$$

Since $r^2 > 1$, the positive factor $(r^2 - 1)$ can be rejected; and hence $\frac{ds}{d\theta} \gtreqless 0$, according as

$$0 \gtreqless \cos^6\theta + (r^2 - 3)\cos^4\theta - (r^2 - 1)(r^2 + 3)\cos^2\theta + (r^2 - 1).$$

To determine whether the right-hand side of the equation can vanish for any value of θ between α and $\frac{\pi}{2}$, let $\cos^2\theta = x$, and $y = x^3 + (r^2 - 3)x^2 - (r^2 - 1)(r^2 + 3)x + (r^2 - 1)$,

$$\therefore \quad \frac{dy}{dx} = 3x^2 + 2(r^2 - 3)x - (r^2 - 1)(r^2 + 3)$$
$$= 3\left[x - (1 - r^2)\right]\left[x - \left(1 + \frac{r^2}{3}\right)\right].$$

Hence if $1 - r^2 < x < 1 + \frac{r^2}{3}$, $\frac{dy}{dx}$ is negative. Now, $1 - r^2 < 0$,

since $r^2 > 1$; hence the lower limit is negative, and the upper limit is greater than unity; so that there is only one value of x between 0 and 1, which will make y vanish. Now the values $x = 0$, $x = \cos^2 a$, corresponding to $\theta = \frac{\pi}{2}$ and $\theta = a$, lie between 0 and 1 inclusive.

When $x = 0$, $y = r^2 - 1 > 0$; when $x = \cos^2 a$,

$y = -r^3 (r^2 - 1)(r - \sqrt{r^2 - 1}) < 0$, and $\frac{dy}{dx}$ is negative for values of x between 0 and $\cos^2 a$. Hence as x increases from 0 to $\cos^2 a$, y decreases from a positive to a negative value, vanishing once only in the interval; hence as x decreases from $\cos^2 a$ to 0, y increases from a negative to a positive value; hence as θ increases from a to $\frac{\pi}{2}$, the expression

$$\cos^6\theta + (r^2 - 3)\cos^4\theta - (r^2 - 1)(r^2 + 3)\cos^2\theta + (r^2 - 1)$$

increases from a negative to a positive value, vanishing once only for some value $\theta = \beta$ between a and $\frac{\pi}{2}$. When this expression is negative, $\frac{ds}{d\theta} > 0$; but when it is positive, $\frac{ds}{d\theta} < 0$. Hence between $\theta = a$ and $\theta = \beta$, $\frac{ds}{d\theta} > 0$; but between $\theta = \beta$ and $\theta = \frac{\pi}{2}$, $\frac{ds}{d\theta} < 0$.

(3) Between $\theta = \frac{\pi}{2}$ and $\theta = \pi - a$, both terms in $\frac{ds}{d\theta}$ are negative; therefore $\frac{ds}{d\theta}$ is negative.

(4) Between $\theta = \pi - a$ and π, the term $\cos\theta$ is negative, but the other term is positive. Hence $\frac{ds}{d\theta} \gtreqless 0$, according as

$$\frac{(r^2 - 1 + r\sqrt{r^2 - 1} + \cos^2\theta)(r^2 - 1 - r\sqrt{r^2 - 1} + \cos^2\theta)}{(r^2 - \sin^2\theta)^2} \gtreqless -\cos\theta.$$

Both sides are now positive. Hence they may be squared, and multiplied by the positive quantity $(r^2 - \sin^2\theta)^3$, and then the inequality becomes

$$\left[(r^2 - 1 + \cos^2\theta)^2 - r^2(r^2 - 1)\right]^2 \gtreqless (-\cos\theta)^2 (r^2 - \sin^2\theta)^3.$$

This is the reverse of the inequality obtained in the case $\alpha < \theta < \frac{\pi}{2}$. Hence $\frac{ds}{d\theta} \gtreqless 0$, according as

$$\cos^6\theta + (r^2-3)\cos^4\theta - (r^2-1)(r^2+3)\cos^2\theta + (r^2-1) \gtreqless 0.$$

It has been already proved that

$$x^3 + (r^2-3)x^2 - (r^2-1)(r^2+3)x + r^2 - 1$$

diminishes as x increases from $1 - r^2$ to $1 + \frac{r^2}{3}$. These limiting values of x include $\cos^2\alpha$ and 1 between them. Hence

$\cos^6\theta + (r^2-3)\cos^4\theta - (r^2-1)(r^2+3)\cos^2\theta + (r^2-1)$ diminishes as $\cos^2\theta$ increases from $\cos^2\alpha$ to 1. Now when $\cos^2\theta = \cos^2\alpha$, the above expression is equal to the negative quantity $-r^3(r^2-1)(r-\sqrt{r^2-1})$, and when $\cos^2\theta = 1$, it is equal to the negative quantity $-r^4$. Hence the expression is negative between $\theta = \pi - \alpha$ and $\theta = \pi$.

Hence $\frac{ds}{d\theta} < 0$, for $\pi - \alpha < \theta < \pi$.

Combining the results, it follows that $\frac{ds}{d\theta} > 0$, for $0 < \theta < \beta$;

but $$\frac{ds}{d\theta} < 0, \text{ for } \beta < \theta < \pi,$$

where

$$\cos^6\beta + (r^2-3)\cos^4\beta - (r^2-1)(r^2+3)\cos^2\beta + r^2 - 1 = 0.$$

Also it has been shown that one and only one acute angle β satisfying this equation does exist. Hence s is a maximum when $\theta = \beta$. Also s is a minimum when $\theta = 0$, or π; viz., s is then zero.

Hence the ratio of the maximum piston velocity to the velocity of the crank-pin is

$$\sin\beta + \frac{\sin\beta\cos\beta}{\sqrt{r^2 - \sin^2\beta}},$$

where β is the acute angle which satisfies the equation

$$\cos^6\beta + (r^2-3)\cos^4\beta - (r^2-1)(r^2+3)\cos^2\beta + r^2 - 1 = 0.$$

The Effect of Alteration in the Length of the Connecting-Rod on the position of the Crank when the Piston moves at its greatest Velocity.—An alteration in the value of r affects the value of β, and therefore the value of the maximum piston velocity, or of S. Accordingly the next step is to trace the changes in β and S as r increases from 1 to ∞.

The relation between r and β can be written

$$r^4\cos^2\beta - r^2\sin^4\beta + \sin^6\beta = 0,$$

which shows that there are two values of r^2 corresponding to each value of β.

Now $r^2 = \dfrac{\sin^4\beta \pm \sin^3\beta\,\sqrt{\sin^2\beta - 4\cos^2\beta}}{2\cos^2\beta}$. The upper sign belongs to the greater value of r. (Both values of r^2 are positive, and both are greater than unity: see the verification at the end of the Paper.)

In order that r^2 may be real, the quantity under the root cannot be negative; therefore $\sin^2\beta - 4\cos^2\beta \geqq 0$, and $\tan^2\beta \geqq 4$, and $\tan\beta \geqq 2$, for β is acute.

The angle whose tangent is 2 is $63^\circ\,26'\,5{\cdot}8''$. Hence $63^\circ\,26'\,5{\cdot}8'' < \beta < 90^\circ$. When $\tan\beta = 2$, $r^2 = \frac{8}{5}$, $r = 2\sqrt{\frac{2}{5}} = 1{\cdot}265\ldots$.

Next

$$r^2 - \sin^2\beta = \tfrac{1}{4}\tan^2\beta\,(2\sin^2\beta - 4\cos^2\beta \pm 2\sin\beta\,\sqrt{\sin^2\beta - 4\cos^2\beta})$$

$$\sqrt{r^2 - \sin^2\beta} = \tfrac{1}{2}\tan\beta\,(\sin\beta \pm \sqrt{\sin^2\beta - 4\cos^2\beta}.$$

Hence
$$S = \sin\beta + \frac{2\sin\beta\cos\beta}{\tan\beta\,(\sin\beta \pm \sqrt{\sin^2\beta - 4\cos^2\beta})}$$

$$= \sin\beta + \tfrac{1}{2}(\sin\beta \mp \sqrt{\sin^2\beta - 4\cos^2\beta})$$

$$= \tfrac{1}{2}(3\sin\beta \mp \sqrt{\sin^2\beta - 4\cos^2\beta}),$$

where the upper sign belongs to the greater value of r corresponding to β.

It will next be shown that as r increases from 1 to ∞, β diminishes from 90° to $63^\circ\,26'\,5{\cdot}8''$, and then increases to 90°; whilst S diminishes continually from 2 to 1.

If $\cos^2\beta = x$, and $r^2 = z$, then

$$x^3 + (z-3)\,x^2 - (z^2 + 2z - 3)\,x + z - 1 = 0.$$

Hence when $x = 0$, $z = 1$ or $z = \infty$.

Solving for z,

$$z = \frac{(1-x)^2 \pm (1-x)^{\frac{3}{2}}\,(1-5x)^{\frac{1}{2}}}{2x}$$

When $\tan\beta = 2$, $\cos\beta = \dfrac{1}{\sqrt{5}}$ and $x = \cos^2\beta = \frac{1}{5}$.

Now $\tan^{-1}2 < \beta < \dfrac{\pi}{2}$, $\frac{1}{5} > \cos^2\beta > 0$, $\frac{1}{5} > x > 0$. Also the limits for the range of z are 1 and ∞.

$$\frac{dz}{dx} = \tfrac{1}{2} - \frac{1}{2x^2} \pm \tfrac{1}{2}\begin{bmatrix} -\tfrac{3}{2}(1-x)^{\frac{1}{2}}(1-5x)^{\frac{1}{2}}x^{-1} \\ -\tfrac{5}{2}(1-x)^{\frac{3}{2}}(1-5x)^{-\frac{1}{2}}x^{-1} \\ -(1-x)^{\frac{3}{2}}(1-5x)^{\frac{1}{2}}x^{-2} \end{bmatrix}$$

$$\therefore \frac{dz}{dx} = \frac{(1-x)^{\frac{1}{2}}}{2x^2(1-5x)^{\frac{1}{2}}}\begin{bmatrix} -(1+x)(1-x)^{\frac{1}{2}}(1-5x)^{\frac{1}{2}} \\ \pm(5x^2+2x-1) \end{bmatrix}$$

Taking first

$$z = \frac{(1-x)^2 - (1-x)^{\frac{3}{2}}(1-5x)^{\frac{1}{2}}}{2x}$$

$$\frac{dz}{dx} = \frac{(1-x)^{\frac{1}{2}}}{2x^2(1-5x)^{\frac{1}{2}}}\left[1-2x-5x^2-(1-5x)^{\frac{1}{2}}(1-x)^{\frac{1}{2}}(1+x)\right].$$

Because $0 < x < \frac{1}{5}$, $1-2x-5x^2 > 0$;

and $\frac{dz}{dx} > 0$, if $1-2x-5x^2 > (1+5x)^{\frac{1}{2}}(1-x)^{\frac{1}{2}}(1+x)$.

Both sides being positive, may be squared, and the condition reduces to $16x^3 + 20x^4 > 0$, which is satisfied.

Hence z increases as x increases from 0 to $\frac{1}{5}$. When $x = 0$, $z = 1$; when $x = \frac{1}{5}$, $z = \frac{8}{5}$.

Taking next

$$z = \frac{(1-x)^2 + (1-x)^{\frac{3}{2}}(1-5x)^{\frac{1}{2}}}{2x},$$

$$\frac{dz}{dx} = \frac{x^2-1}{2x^2} + \tfrac{1}{2}\begin{bmatrix} -\tfrac{3}{2}(1-x)^{\frac{1}{2}}(1-5x)^{\frac{1}{2}}x^{-1} \\ -\tfrac{5}{2}(1-x)^{\frac{3}{2}}(1-5x)^{-\frac{1}{2}}x^{-1} \\ -(1-x)^{\frac{3}{2}}(1-5x)^{\frac{1}{2}}x^{-2} \end{bmatrix}$$

Since $0 < x < \frac{1}{5}$, every term on the right-hand side of the last equation is negative; therefore $\frac{dz}{dx} < 0$. Hence as x increases from 0 to $\frac{1}{5}$, z decreases from ∞ to $\frac{8}{5}$; and $\therefore$ as x decreases from $\frac{1}{5}$ to 0, z increases from $\frac{8}{5}$ to ∞. Taking the two values of z in succession, as z increases from 1 to $\frac{8}{5}$, x increases from 0 to $\frac{1}{5}$; and if z increase from $\frac{8}{5}$ to ∞, x will decrease from

$\frac{1}{5}$ to 0. Hence as r increases from 1 to $2\sqrt{\frac{2}{5}}$, β decreases from $\frac{\pi}{2}$ to $\tan^{-1} 2$; and as r increases from $2\sqrt{\frac{2}{5}}$ to ∞, β increases from $\tan^{-1} 2$ to $\frac{\pi}{2}$.

Determination of the Effect of an Alteration in the Length of the Connecting-rod on the maximum Velocity of the Piston.—Now for $1 < r < 2\sqrt{\frac{2}{5}}$, $\frac{\pi}{2} > \beta > \tan^{-1} 2$,

$$S = \tfrac{1}{2}(3 \sin \beta + \sqrt{\sin^2 \beta - 4 \cos^2 \beta}),$$

$\frac{dS}{d\beta} = \frac{1}{2}\left(3 \cos \beta + \frac{5 \sin \beta \cos \beta}{\sqrt{\sin^2 \beta - 4 \cos^2 \beta}}\right)$, therefore $\frac{dS}{d\beta} > 0$. Hence as β decreases from $\frac{\pi}{2}$ to $\tan^{-1} 2$, S decreases also, viz. from 2 to $\frac{3}{\sqrt{5}}$.

Next for $2\sqrt{\frac{2}{5}} < r < \infty$, $\tan^{-1} 2 < \beta < \frac{\pi}{2}$,

$$S = \tfrac{1}{2}(3 \sin \beta - \sqrt{\sin^2 \beta - 4 \cos^2 \beta}),$$

$\frac{ds}{d\beta} = \frac{1}{2}\left(3 \cos \beta - \frac{5 \sin \beta \cos \beta}{\sqrt{\sin^2 \beta - 4 \cos^2 \beta}}\right)$. Hence $\frac{dS}{d\beta} < 0$, if $3\sqrt{\sin^2 \beta - 4 \cos^2 \beta} < 5 \sin \beta$, which is the case.

Hence as β increases from $\tan^{-1} 2$ to $\frac{\pi}{2}$, S decreases from $\frac{3}{\sqrt{5}}$ to 1.

Recapitulation of Results.—The acute angle, β, between the crank and the line of motion of the piston, when the piston is moving with the greatest velocity, is given by the equation

$$\cos^6 \beta + (r^2 - 3) \cos^4 \beta - (r^2 - 1)(r^2 + 3) \cos^2 \beta + r^2 - 1 = 0.$$

Further, as r increases from 1 to $2\sqrt{\frac{2}{5}}$, β decreases from $\frac{\pi}{2}$ to $\tan^{-1} 2$, and S, which is equal to $\frac{1}{2}(3 \sin \beta + \sqrt{\sin^2 \beta - 4 \cos^2 \beta})$, which is equal to $\frac{1}{2}\left(3 \sin \beta + \sqrt{\frac{5}{2} \cos(\pi - 2\beta) - \frac{3}{2}}\right)$, decreases from 2 to $\frac{3}{\sqrt{5}}$. Also as r increases from $2\sqrt{\frac{2}{5}}$ to ∞, β increases from $\tan^{-1} 2$ to $\frac{\pi}{2}$; and S, which is equal to $\frac{1}{2}(3 \sin \beta - \sqrt{\sin^2 \beta - 4 \cos^2 \beta})$,

which is equal to $\frac{1}{2}\left(3 \sin \beta - \sqrt{\frac{5}{2} \cos (\pi - 2\beta) - \frac{3}{2}}\right)$, decreases from $\frac{3}{\sqrt{5}}$ to 1.

Solution of the Cubic Equation which determines the Position of the Crank when the Piston moves at its greatest Velocity.—It remains to give a practical method for solving the equation in β. If $\cos^2 \beta = x$, and $r^2 = z$, the equation becomes

$$x^3 + (z - 3)\, x^2 - (z^2 + 2\, z - 3)\, x + z - 1 = 0.$$

If $x = \mathrm{A}\, t + \mathrm{B}$ where A, B, and t will be determined later, then

$$\begin{aligned} &\mathrm{A}^3\, t^3 + \mathrm{A}^2\, t^2\, (3\, \mathrm{B} + z - 3) \\ &+ \mathrm{A}\, t\, (3\, \mathrm{B}^2 + 2\, \mathrm{B}\, (z - 3) - (z^2 + 2\, z - 3)) \\ &+ [\mathrm{B}^3 + \mathrm{B}^2 (z - 3) - \mathrm{B} (z^2 + 2\, z - 3) + z - 1] = 0. \end{aligned}$$

Now when $\mathrm{B} = \frac{1}{3}\, (3 - z)$, the equation becomes

$$t^3 - \frac{4\, t\, z^2}{3\, \mathrm{A}^2} + \frac{11\, z^3 - 27\, z^2}{27\, \mathrm{A}^3} = 0.$$

Now let α be a subsidiary angle, then, whatever its value, $\cos^3 \alpha - \frac{3}{4} \cos \alpha - \frac{1}{4} \cos 3\, \alpha = 0$.

When $\mathrm{A} = \frac{4}{3}\, z$, and $t = \cos \alpha$, $\cos 3\, \alpha = \frac{27}{16\, z} - \frac{11}{16}$,

$\therefore \cos 3\alpha = \frac{27}{16\, r^2} - \frac{11}{16}$, $\cos^2 \beta = x = \mathrm{A}\, t + \mathrm{B} = \frac{4}{3} r^2 \cos \alpha + 1 - \frac{r^2}{3}$,

$\cos 2\, \beta = \frac{8}{3} r^2 \cos \alpha - \frac{2\, r^2}{3} + 1$.

Hence the complete solution of the problem may be effected thus:—Solve for α the equation $\cos 3\, \alpha = \frac{27}{16\, r^2} - \frac{11}{16}$. If $\alpha = \alpha_0$ be one solution, then $\alpha_0 + \frac{2\, \pi}{3}$, $\alpha_0 + \frac{4\, \pi}{3}$ are also solutions.

One only of these solutions will give a possible value for the acute angle β, satisfying the equation

$$\cos 2\, \beta = \tfrac{8}{3}\, r^2 \cos \alpha - \tfrac{2}{3}\, r^2 + 1.$$

This value of β is the angle between the crank and the line of motion of the piston, when the piston-velocity is a maximum.

Then the ratio of the maximum piston-velocity to the velocity of the crank-pin is

$$\tfrac{1}{2}\left(3\sin\beta - \sqrt{\tfrac{5}{2}\cos(\pi - 2\beta) - \tfrac{3}{2}}\right),$$

if, as in all practical cases, $r > \sqrt{\frac{8}{5}}$; but it is

$$\tfrac{1}{2}\left(3\sin\beta + \sqrt{\tfrac{5}{2}\cos(\pi - 2\beta) - \tfrac{3}{2}}\right)$$

if $$1 < r < \sqrt{\tfrac{8}{5}}.$$

Examples.—As practical illustrations, the cases in which $r = 3, 4, 5$ are worked out numerically.

(I.) $r = 3$, $\cos 3\alpha = -\frac{1}{2} = \cos 120°$, $\alpha = 40°$, $160°$, or $280°$, $\cos 2\beta = 24\cos\alpha - 5$, and it is necessary to take $\alpha = 280°$,

$$\begin{aligned}\cos\alpha &= \sin 10° = 0{\cdot}1736482\\ \cos 2\beta &= -0{\cdot}8324432\\ \cos(180° - 2\beta) &= \quad 0{\cdot}8324432\\ &= \cos 33°\ 38'\ 58''\\ \beta &= 73°\ 10'\ 31''\end{aligned}$$

$$\begin{aligned}S &= \tfrac{1}{2}\left(3\sin 73°\ 10'\ 31'' - \sqrt{-1{\cdot}5 + \tfrac{5}{2}(0{\cdot}8324432)}\right)\\ &= \tfrac{1}{2}\left(3\,(0{\cdot}9571947) - \sqrt{0{\cdot}581108}\right)\\ &= 1{\cdot}055 \text{ nearly.}\end{aligned}$$

(II.) $r = 4$, $\cos 3\alpha = -0{\cdot}5820313$, $\cos(180° - 3\alpha) = 0{\cdot}5820313 = \cos 54°\ 24'\ 23''{\cdot}3$, $\alpha = 41°\ 51'\ 52''{\cdot}2$ is one solution.

The other solutions are $161°\ 51'\ 52''{\cdot}2$ and $281°\ 51'\ 52''{\cdot}2$.

Taking
$$\begin{aligned}\alpha &= 281°\ 51'\ 52''{\cdot}2\\ \cos\alpha &= \sin 11°\ 51'\ 52''{\cdot}2 = 0{\cdot}2055979\\ \cos 2\beta &= -0{\cdot}8944896\\ \cos(180° - 2\beta) &= 0{\cdot}8944896\\ &= \cos 26°\ 33'\ 25''{\cdot}4\\ \beta &= 76°\ 43'\ 17''{\cdot}3\end{aligned}$$

$$\begin{aligned}S &= \tfrac{1}{2}\left(3\sin 76°\ 43'\ 17''{\cdot}3 - \sqrt{-\tfrac{3}{2} + \tfrac{5}{2}(0{\cdot}8944896)}\right)\\ &= \tfrac{1}{2}\left(3\,(0{\cdot}9732650) - \sqrt{0{\cdot}736224}\right)\\ &= 1{\cdot}031 \text{ nearly.}\end{aligned}$$

(III.) $r = 5$, $\cos 3\alpha = -0{\cdot}62$, $\cos(180° - 3\alpha) = 0{\cdot}62$
$$\begin{aligned}&= \cos 51°\ 41'\ 1''{\cdot}9\\ \alpha &= 42°\ 46'\ 19''{\cdot}4.\end{aligned}$$

The other values of α are $162°\ 46'\ 19''{\cdot}4$ and $282°\ 46'\ 19''{\cdot}4$.

Taking the last, $\cos 2\beta = \frac{200}{3} \sin 12° 46' 19''\cdot 4 - \frac{47}{3}$

$$= \frac{200}{3}(0\cdot 2210728) - \frac{47}{3}$$

$$\cos (180° - 2\beta) = 0\cdot 92848 = \cos 21° 48' 3''\cdot 2$$
$$\beta = 79° 5' 58''\cdot 4$$

$$S = \tfrac{1}{2}\left(3 \sin 79° 5' 58''\cdot 4 - \sqrt{-1\cdot 5 + \tfrac{5}{2}(0\cdot 92848)}\right)$$
$$= \tfrac{1}{2}\left(3(0\cdot 9819572) - 0\cdot 9062\right)$$
$$= 1\cdot 019 \text{ nearly.}$$

A Verification.—It remains only to verify the statement that the two values of r^2 given by

$$\frac{\sin^4\beta \pm \sin^3\beta \sqrt{\sin^2\beta - 4\cos^2\beta}}{2\cos^2\beta}$$

are both positive and greater than unity, when $\tan\beta > 2$.

Taking the positive sign, the expression is obviously positive. Taking the negative sign, it is necessary to show that

$\sin^4\beta > \sin^3\beta \sqrt{\sin^2\beta - 4\cos^2\beta}$, or $\sin\beta > \sqrt{\sin^2\beta - 4\cos^2\beta}$, or $4\cos^2\beta > 0$, which is the case.

To show that both values are greater than 1, it is sufficient to show that the smaller value is greater than 1. Hence it must be shown that

$$\sin^4\beta - \sin^3\beta \sqrt{\sin^2\beta - 4\cos^2\beta} > 2\cos^2\beta,$$

or $$\sin^4\beta - \sin^3\beta \sqrt{5\sin^2\beta - 4} > 2 - 2\sin^2\beta,$$

or $$\sin^4\beta + 2\sin^2\beta - 2 > \sin^3\beta \sqrt{5\sin^2\beta - 4}.$$

Now the left-hand side is positive, because

$$\sin\beta > \sin(\tan^{-1} 2),$$

$$\therefore \quad \sin\beta > \frac{2}{\sqrt{5}},$$

$$\therefore \sin^4\beta + 2\sin^2\beta > \frac{16}{25} + \frac{8}{5}, \text{ or } > \frac{56}{25}, \text{ or } > 2.$$

Hence both sides may be squared, and the condition becomes $0 > 4(\sin^4\beta - 1)(1 - \sin^2\beta)^2$, $0 > -4(1 + \sin^2\beta)\cos^6\beta$, which is satisfied.

OBITUARY.

JAMES ABERNETHY, Past-President, who died at his country residence, Whiteness, Broadstairs, on the 8th March, 1896, at the age of eighty-one, was one of the oldest and most distinguished members of the Institution, into which he was elected on the 5th March, 1844. His long professional career of over sixty years was one of constant activity and devotion to the calling in which he early attained a high position and won universal respect. Though at the date of his decease he was approaching the completion of his eighty-second year, his latter days were not marred by any of the infirmities which age brings in its train. Work was his absorbing pleasure to the last, his keenness of perception and energy of purpose showed no signs of becoming impaired, and his physique but slight symptoms of diminishing strength from the wear and tear which a long life of responsibility and anxiety might seem well calculated to entail.

Mr. Abernethy was one of the small remaining band of engineers who held a prominent position in the profession when the railway mania was in full force; but even at that date he had already come to be regarded as a specialist in dock and harbour works, and it is in connection with this branch of Engineering that his name and fame have since been, and will remain, associated. The various harbour and dock works which he designed and executed, or enlarged and deepened, in England, Scotland, Ireland and Wales, as well as abroad, bear testimony to his skill as a marine engineer.

Born at Aberdeen on the 14th June, 1814, James Abernethy was sent at the early age of five to a school in that city, his father, Mr. George Abernethy, being at that time manager of some small mechanical works there. In 1823 the latter left Scotland to superintend similar works at Dowlais, near Swansea, owned by Mr. John Guest, whence five years later he removed to London to take charge of an iron foundry in Southwark. Thence James was entrusted to the tender mercies of a schoolmaster named Smith, whose school was at Cotherstone, near Barnard Castle, and who on his visits to London made the *Belle Sauvage* on Ludgate Hill his headquarters. James and his brother, George, sailed with their mentor in a brig from the Thames to Stockton.

Thence a carriage drive brought them to Cotherstone, which has been fixed upon as the original study of Charles Dickens' description of Dotheboys Hall. Whether this was the identical school or not, the system was at any rate similar. The boys' clothes were taken from them on arrival, only to be returnable on Sundays for the purpose of attending church, and the apparel substituted would have ill become workhouse lads. The dormitory consisted of the upper floor of an old barn and the dining-hall was underneath. Holidays were unknown, or at any rate unhoped for, and most of the boys were remembered as having developed debased and cruel dispositions, a logical sequence of the treatment to which they were subjected. Fortunately, one day a clerical uncle, John Abernethy, visited his nephews, and, realizing their unhappy condition, took them to his Manse at Bolton, near Haddington, where they attended the Grammar School for the two succeeding years. At the end of that time James commenced work with his father, at that date Resident Engineer at the London Docks under Mr. Henry Robinson Palmer,[1] and in the latter gentleman's office, in Ratcliff Highway, he served his first apprenticeship as an engineer.

In 1833 Mr. Abernethy went to Sweden to investigate a manganese mine, and remained there for some four years. There is no engineering work of any importance to ascribe to him during that interval, but it may be observed that those few years, in which, as his diary records, he found ample time for fishing, riding, and sketching—the last-named recreation being always a favourite of his—constituted the holiday period of his life.

More regular and continuous work awaited him in 1839, in which year he went to Goole Docks as Assistant Engineer to Mr. George Leather of Leeds. When that undertaking was finished, he took a similar post on the Aire and Calder Canal,[2] while later his services were enlisted during the construction of the North Midland Railway between Wakefield and Leeds. It was however in 1840 that Mr. Abernethy's ability first came to be clearly recognised. Early in that year he was appointed Resident Engineer at Aberdeen Harbour, where by systematic dredging the tidal flow was improved, in less than twelve months, to the extent that the water over the bar increased in depth from 2 feet to 5 feet at low tide. The Board then invited competitive designs for the conversion of a portion of the tidal harbour into a floating dock. Mr. Abernethy's plans were selected, but it was stipulated that

[1] Minutes of Proceedings Inst. C.E., vol. iv. p. 6.
[2] *Ibid*, vol. xxvi. p. 32.

before they were put in execution they should be submitted to a London engineer. The designs thus submitted met with severe criticism, but the successful candidate was quite equal to the call made upon him to defend them, and brought all further discussion to a crisis by a reference to the slender practical experience of his critic. The interview closed with the direction from the chairman of the Board, who had accompanied him to London, that he might return to Scotland and be his own chief engineer. He thus became at the age of twenty-eight Engineer-in-Chief and never afterwards held a subordinate position.

The improvements[1] in the harbour of his native city took some years to complete, and meanwhile he was consulted upon various other projects, and constructed a fishing-harbour at Boddam, near Peterhead, for the Earl of Aberdeen. In 1844 he was appointed a Surveying Officer under the Preliminary Inquiries Act, and served in that capacity for the remaining period of eight years during which the Act was in force, reporting upon the condition of the Rivers Clyde, Tyne and Ribble, and the Ports of Liverpool, Birkenhead, Glasgow, Bristol, Newcastle and Belfast.

It was while Harbour Engineer at Aberdeen, which he did not finally leave until 1851, that Mr. Abernethy was appointed Chief Engineer to the port of Swansea, where, as at Aberdeen, his work was at first the conversion of a portion of the tidal harbour into a floating dock. Subsequently he constructed at Swansea the South Dock in 1858, the Prince of Wales Dock in 1881, and in 1893 he furnished designs for a new dock, his connection with that Port thus extending over a period of half a century. In 1862 he presented to the Institution a Paper describing the South Dock at Swansea and the works at Blyth and at Silloth carried out by him.[2]

In 1853 Mr. Abernethy was engaged upon new and important works at Birkenhead, where the Great Float was finished in the following year, and shortly afterwards he became involved in a memorable conflict of engineering opinion. This arose with regard to the projected scheme for a great low-water basin between the dock and the River Mersey; the proposal, which was wholly at variance with Mr. Abernethy's views, being to maintain this basin at a depth of 15 feet below low water by a system of subaqueous sluices, while his advice was to substitute a floating dock in its stead. This advice was so far accepted that application was made to Parliament to sanction his scheme. James Meadows

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 323.
[2] *Ibid*, vol. xxi. p. 309.

Rendel and Robert Stephenson, however, opposed it strenuously in Committee, and the matter was referred to two experts, of whom Stephenson was one, to report upon. This report was in due time presented to the Committee, whereupon Mr. Abernethy protested so strongly against the way in which the evidence had been represented that the Committee decided to ignore the report in its entirety, and for a time the rival schemes remained in abeyance. In 1856, upon the transfer of the Birkenhead Dock property to the Mersey Docks and Harbour Board and the appointment of Mr. John Hartley as Engineer, Parliament decided that the plan of subaqueous sluicing was to be followed. Upon the first opening of the sluices, however, the rush of the incoming water seriously threatened the stability of the works. They were closed with all expedition, but none too soon to avoid a catastrophe, and were not used again. Then Mr. Abernethy's turn arrived and the floating dock was authorised and constructed.[1] While residing at Birkenhead, he designed works to improve the harbours of Fraserburgh and Lossiemouth and advised upon various other fishing-harbours in Scotland.

In 1854 Mr. Abernethy took an office in Parliament Street, Westminster, and permanently established himself in London. More works, however, were required at Birkenhead, and during the next two years he was busy designing and constructing graving docks and river walls between Woodside Ferry and Messrs. Laird's Ship-building Yard. In 1856–60 he undertook his first work at Newport (Mon.), viz., the extension of the existing dock and the introduction of hydraulic machinery for the shipment of coal. At the same time he was engaged upon the piers and dock at Silloth in the Solway Firth, Watchet Harbour, Falmouth Piers and Graving Dock, and the Harbours of Stranraer and Port Patrick.

The enumeration of these works, which were simultaneously carried out under his direction at this period, is evidence that Mr. Abernethy was then perhaps in the height of his fame, and his removal to London at the age of forty was certainly opportunely timed. Up to this age he had won a high reputation as a practical engineer, and henceforth his presence in Westminster enabled him to enter upon an additional practice as a consulting engineer, and to continue for forty years as a supporter or opponent of the plans of others in the Committee Rooms of the Houses of Parliament. In this branch of the practice of a leading engineer he proved scarcely less successful than he had already been on the construc-

[1] Minutes of Proceedings Inst. C.E., vol. xxviii. p. 518, and vol. xxix. p. 5.

tive side. He could never be induced to support any scheme in which he did not believe, nor would he oppose a scheme which he knew to be sound merely for the sake of a fee.

In 1861 Mr. Abernethy was in Spain for the purpose of inspecting and reporting upon a projected line of railway from Aranjuez to Cuenca, but the plans submitted to him were so inaccurate that he had no alternative but to disapprove the scheme. In the following year, however, he accepted the position of chief engineer to the Turin and Savona Railway, a line 120 miles in length, through difficult country. About this time he became consulting engineer to the Grand Canal Cavour, designed to irrigate some 300,000 acres adjoining the banks of the River Po. This, like the previous scheme, was financed in England, but business arrangements of a most unsatisfactory nature had been entered into in Italy. Mr. Abernethy reported strongly against the methods adopted for carrying out the works, and by so doing secured some improvement; but the shareholders in the undertaking nevertheless suffered heavily.

In 1867, in company with the late Mr. J. R. McClean, Past-President Inst. C.E., he went to Egypt, relative to the improvement of Alexandria Harbour, and during a stay of some weeks was courteously entertained by the Khedive. During the following year he had an interview with the late Emperor Napoleon III. on the subject of his and Sir John Fowler's scheme of international communication between England and France, under which large steamers were to be built designed to convey the trains across the channel. The Bill, however, was rejected in Parliament in 1870. In that year Mr. Abernethy was appointed a member of an International Commission for the regulation of the River Danube at Vienna. Among other works of importance upon which he was engaged are the Alexandra Docks, Newport, opened in 1868; the Alexandra Dock at Hull, 1881;[1] the reclamation of Lake Aboukir, Egypt, 1888–89;[2] Torquay Pier, 1890–94; Bute Docks, Cardiff, 1877–91. He also prepared designs for Port Victoria, 1888–89; the Midland Railway Company's Dock at Morecambe, now before Parliament; a reservoir at Merthyr Tydfil; and a dock at Tranmere, 1893. He served on the Royal Commissions on Metropolitan Sewage Discharge (1882) and Irish Public Works (1889) and on a Belgian Royal Commission which issued a report upon the construction of harbours on sandy coasts.

Mr. Abernethy was Consulting Engineer to the Manchester

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[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 144.

[2] *Ibid*, vol. ci. p. 189.

Ship Canal Company from 1887 to 1892, having been previously connected with the project from its inception in 1880, at which time he advocated strongly, and his advice ultimately decided, that the scheme to be submitted to Parliament should be that of a ship canal as opposed to a system of training the River Mersey. He lived to see this, the greatest work with which he was associated, opened for traffic and the City of Manchester a seaport.

At the time of his decease Mr. Abernethy, with the assistance of his sons, James and George, whom he took into partnership in 1893, and who had been for many years closely associated with him in his business, was engaged in deepening and extending the Harbour of Fraserburgh in Scotland, with which he first became connected professionally in 1856.

At the age of twenty-four Mr. Abernethy married the eldest daughter of the late Mr. John Neill of Wakefield and Leeds, whom he leaves a widow with three sons and three daughters. His third son, Harold, predeceased him.[1] In 1859 he purchased some land at Kingsgate in the Isle of Thanet, where in the home he had made he breathed his last on the 8th March, 1896, having by his long residence and genial disposition won the respect of the entire neighbourhood. His leisure hours spent there during the past few years were largely occupied in painting, for which he had considerable talent.

Mr. Abernethy was elected President of the Institution on the 21st December, 1880, and in the following January delivered an inaugural address,[2] in which he reviewed the progress of the mercantile marine and the consequent development of intercommunication between this country and all parts of the globe. He frequently took part in discussions, as may be seen by a reference to the indexes to the Minutes of Proceedings.

EDMUND SCOTT BARBER, born at Newport, Mon., on the 16th August, 1845, was the son of the late Mr. Edmund Scott Barber,[3] a well-known Mining Engineer in South Wales. On the death of the latter in 1854, the family removed to Brussels; but after about three years returned to this country and settled first in Cornwall and subsequently at Plymouth, where Edmund was educated at private schools. He was not yet seventeen when, in

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[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 363.
[2] *Ibid*, vol. lxiv. p. 2. [3] *Ibid*, vol. xiv. p. 126.

January, 1862, he was articled to the late Mr. Alexander Bassett,[1] who had been in partnership with his father and had succeeded to that gentleman's practice in South Wales. Among other posts held by Mr. Bassett was that of County Surveyor of Glamorganshire; and during the nine years of his connection with that engineer, Edmund Barber obtained considerable experience in road and bridge work and in the erection of public buildings. He also acted as Mr. Bassett's assistant on the construction of the Pontypridd Waterworks and of the Cowbridge Railway, in the preparation of the surveys for the Alexandra Docks, Newport, of which the late Mr. Abernethy[2] was the Engineer-in-Chief, and on railway work in Carmarthenshire.

In June, 1873, Mr. Barber was appointed to the Public Works Department of Ceylon, and for the next six years was engaged on irrigation works in that island. On the reduction of the establishment, he left Ceylon in August, 1879, and was taken into partnership by Mr. Bassett, for whom he acted as County Surveyor of Glamorganshire. In the following December he was selected from over seventy candidates for the post of District Engineer at Kingston, Jamaica. The work there involved the maintenance, and in many cases the erection, of public buildings, bridges, roads, telegraph and telephone lines and stations, lighthouses and piers. These works represented a large expenditure, considerably increased after a hurricane which occurred in August, 1880, and were satisfactorily carried out by Mr. Barber, who was commended by the Director of Public Works of the island for his "zeal and devotion to duty." In August, 1883, he was appointed Colonial Engineer of British Honduras. Long service in a tropical climate, however, had begun to tell upon his health, and he was obliged to take sick leave in the following June.

Mr. Barber did not return to British Honduras, but, in May, 1885, re-entered the service of the Ceylon Public Works Department. During the next few years he was engaged mainly on irrigation surveys; and, in June, 1892, he was appointed Acting Engineer of the Kalmunai District, in addition to his ordinary duties. In 1894 he was placed in charge of the Dandagama District, but at the end of that year he retired under medical advice and returned to England. In September, 1895, he was appointed Director and Engineer to the East Devon Tile and Brick Company. His health, however, unfortunately broke down.

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[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 377.

[2] *Ante*, p. 402.

It was found that he was suffering from cancer in the throat, and after some months of severe pain, borne with fortitude and patience, he died at Exmouth on the 14th January, 1896.

Mr. Barber married, in 1869, Alice, the eldest surviving daughter of Major John Waterfield, 38th Native Infantry. He was elected an Associate of the Institution on the 2nd December, 1873, and was transferred to the class of Member on the 3rd December, 1878.

DANIEL KINNEAR CLARK, born on the 17th July, 1822, was the youngest of the three sons of Daniel Clark, a merchant, of Edinburgh. His taste for mechanics showed itself at an early age; and there is now in the possession of his relatives a MS. entitled "A Descriptive History of the Steam Engine from the Earliest Age," written by young Clark in 1836, when fourteen years old. He commenced life as a teacher of mathematics at the Edinburgh Grammar School. He speedily tired, however, of the drudgery and monotony of teaching, and, in 1839, apprenticed himself to Messrs. Thomas Edington and Sons, of the Phœnix Ironworks, Glasgow. At the expiration of his apprenticeship in 1845, he entered the service of Mr. John Miller, of Edinburgh, and in the following year became principal draughtsman in that gentleman's office. During two of the three years he remained in Edinburgh, Mr. Clark utilised his spare time as assistant editor of the *Practical Mechanic and Engineer's Magazine*. He left Mr. Miller in November, 1848, and then served in the Locomotive Department of the North British Railway.

It was at this period that Mr. Clark came into contact with Messrs. Blackie and Son, a meeting which resulted in the publication of his first book.[1] In order to obtain the necessary materials for this work he visited nearly all the locomotive shops in England and Scotland. His "Railway Machinery" at once established his reputation as an authority on the locomotive engine, and the book of 1855 may still be regarded as a standard work. It was dedicated to Robert Stephenson; and among the letters Mr. Clark received on the subject was one from that engineer upon which he always set special value. Two years before the publication of this book he had presented to the Institution the first of a long series of Papers identified with his name, an "Experimental

[1] "Railway Machinery: a treatise on the mechanical engineering of railways, embracing the principles and construction of rolling and fixed plant," 2 vols. Glasgow, 1855. folio.

Investigation of the Principles of the Boilers of Locomotive Engines,"[1] for which he was awarded a Telford Medal. In 1852, two Papers by him "On the Expansive Working of Steam in Locomotives" were read before the Institution of Mechanical Engineers.[2] Mr. Clark's attention, however, at this period was not entirely devoted to literary work. During its existence he acted as Engineer to the Deep-Sea Fishing Association for Scotland, one outcome of which was a Paper presented to the Institution in 1853, "An Account of the Deep-Sea Fishing Steamer 'Enterprise' with Ruthven's Propeller."[3] For this he was awarded a Council Premium of Books. In October, 1853, he was appointed Locomotive Superintendent of the Great North of Scotland Railway, but considering after a time that residence in Aberdeen, which was one of the conditions of the appointment, was not favourable to his advancement in the profession he resigned that post in March, 1855.

Acting on the advice of several well-known engineers, Mr. Clark determined to start in London as a Consulting Engineer; and, in May, 1855, he took an office at 11, Adam Street, Adelphi, subsequently removing to Buckingham Street, where he resided until his death. Work came quickly. He was appointed by Robert Stephenson Inspector of Locomotives for the Great Indian Peninsular Railway, the duties consisting of the inspection of fifty locomotives, to be examined within two years. He also wrote for the Directors of the Waterford and Kilkenny Railway Company a report on the condition of that property which evoked considerable criticism and discussion. In 1856 he examined and reported on the rolling stock of the Londonderry and Enniskillen Railway, and in November of that year his Paper "On the Improvement of Railway Locomotive Stock and the Reduction of the Working Expenses" was read before the Institution.[4] In that communication, for which he was awarded a Telford Medal, Mr. Clark sought to show that an economy of 50 per cent. might be effected in the working charges of the locomotive stock of the railways of the United Kingdom. In November, 1857, he patented an invention for the consumption of smoke in locomotives using bituminous fuel,[5] which proved successful

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[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 382.

[2] Proceedings Institution of Mechanical Engineers, 1852, pp. 60 and 109.

[3] Minutes of Proceedings Inst. C.E., vol. xiii. p. 370.

[4] *Ibid*, vol. xvi. p. 3.

[5] Patent Office Abridgments of Specifications relating to the Steam Engine, vol. ii. p. 1,477.

and was subsequently applied with good results to stationary engines.

Mr. Clark's work on "Railway Machinery" had meanwhile obtained so great a reputation in the United States that he was asked by Zerah Colburn[1] to collaborate in the production of a supplementary volume which was published in 1860.[2] In the same year another Paper—"On Coal-burning and Feedwater Heating in Locomotive Engines"[3]—for which he obtained a Council Premium of Books—was brought before the Institution. In the following year the charge of the Machinery Department of the International Exhibition of 1862 was entrusted to Mr. Clark. The putting in of the mains to supply steam to the machinery in motion was at that time a difficult task. The mains were laid underground, and much skill and forethought were necessary to get rid of water and to avoid leakage. Mr. Clark carried out the work with ability, tact and an absence of friction worthy of all praise. He received the thanks of the Commissioners of the Exhibition for his services, and a testimonial from the exhibitors in his department. The literary outcome of this work was a cyclopædia of the machinery exhibited[4] and a Paper "On the Locomotive Engines in the International Exhibition of 1862."[5]

In 1868 Mr. Clark was engaged for a Government Commission in a valuation of the rolling-stock of the Irish railways, and in the same year he was similarly occupied in Scotland for the Caledonian Railway Inquiry Commission. In 1869 and in 1871 he went to Egypt for Sir John Fowler to report on the railways of that country, and to prepare a scheme of irrigation for the Egyptian government. His stay was prolonged until 1872 in connection with plans for agricultural railways and for a ship railway at the first cataracts of the Nile at Assouan.

From that time Mr. Clark devoted himself more particularly to literary work. Further contributions to this Institution were, in 1875, an account of the St. Gothard Tunnel,[6] supplemented in 1879 by a description of that work up to its practical completion;[7] in 1876, "The Evaporative Performance of Steam Boilers";[8] in 1878, "On the Strength of Flat Plates and Segmental Ends of

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[1] Minutes of Proceedings Inst. C.E., vol. xxxi. p. 212.

[2] "Recent Practice in the Locomotive Engine." Glasgow, 1860, folio.

[3] Minutes of Proceedings Inst. C.E., vol. xix. p. 546.

[4] "The Exhibited Machinery of 1862: a Cyclopædia of the Machinery represented at the International Exhibition." London, 1864, 8vo.

[5] Proceedings Institution of Mechanical Engineers, 1863, p. 78.

[6] Minutes of Proceedings Inst. C.E., vol. xlii. p. 228.

[7] *Ibid*, vol. lvii. p. 239.

[8] *Ibid*, vol. xlvi. p. 242.

Boilers and other Cylinders,"[1] and "On the Progress of Machinery in Foreign Countries";[2] and in 1883, "On the Behaviour of Steam in the Cylinders of Locomotives during Expansion."[3] He also prepared the Subject-Index to Vols. i.–lviii. of the Minutes of Proceedings, and was for many years a constant contributor to the Abstracts of Papers in Foreign Transactions and Periodicals. In 1877 Mr. Clark produced "A Manual of Rules, Tables and Data for Mechanical Engineers,"[4] a work of the greatest use to engineers, in the preparation of which he was occupied for upwards of four years. "Tramways: their Construction and Working" appeared in 1878,[4] a supplementary volume being published in 1882, and a revised and enlarged edition in 1895. It has already been mentioned that as early as 1857 Mr. Clark turned his attention to the combustion of fuel and the prevention of smoke. For many years he investigated this subject, and in 1879 he published "Fuel: its Combustion and Economy."[4] Two years later he carried out, in connection with the Smoke Abatement Exhibition at South Kensington, an elaborate series of tests of coal, and of heating and cooking appliances, the results being embodied in a report of the Smoke Abatement Committee published in 1883.[5]

The most important of Mr. Clark's recent works is "The Steam Engine: a Treatise on Steam Engines and Boilers,"[4] which appeared in 1892. As far back as 1885 he had published "An Elementary Treatise on Steam and the Steam Engine,"[4] but in the later book he treated the subject exhaustively, making it in fact an epitome of his life-work. In 1892 he brought out also "The Mechanical Engineer's Pocket Book,"[4] which contains a mass of original and valuable information. The last years of Mr. Clark's life were embittered by failing health, which forbade any mental exertion except at rare intervals. There can be but little doubt that this condition was the result of many years of overwork. For years he took no holiday and worked late night after night. To add to his troubles, the books which had made him famous were, from a pecuniary point of view, failures, owing to the extremely conscientious manner in which he laboured to make them as exhaustive and as perfect as possible. He was very patient in his long illness and seldom complained. He died at his residence, 8, Buckingham Street, Adelphi, on the 22nd January, 1896, in the seventy-fourth year of his age.

[1] *Ibid*, vol. liii. p. 170.
[2] *Ibid*, vol. lv. p. 286.
[3] *Ibid*, vol. lxxii. p. 275.
[4] This work is in the Library of the Institution.
[5] This Report is in the Library of the Institution.

Mr. Clark will be known more by his books than as an engineer. By original research and literary work of a high order he has rendered valuable and lasting assistance to the profession. He was elected an Associate on the 7th February, 1854, and was transferred to the class of Member on the 27th of January, 1863.

THOMAS HOWARD, who died at Weston-super-Mare, on the 17th of January, 1896, was the first Engineer to the Bristol Docks under the corporation of that city, which post he occupied for more than twenty-seven years. At the meeting of the Docks Committee held on the 20th of January the following resolution was passed:—"That this Committee hear with great regret of the death of Mr. Thomas Howard, formerly for many years Engineer to the Docks Estate of the Corporation, and desire to place on record their high appreciation of the valuable services rendered by him in that capacity."

Born on the 5th of November, 1816, Thomas Howard commenced his engineering career as an Assistant to Mr. T. E. Blackwell,[1] who was in private practice as a civil engineer in Bristol. Besides being connected with several railways and canals, Mr. Blackwell acted as consulting engineer to the Bristol Docks. On his resignation of the latter office in 1855, Mr. Howard was appointed Dock Engineer, this being the first appointment of an engineer devoting his time exclusively to the duties of that post. Mr. Howard at once devoted his attention to the improvement of the river and also to plans for its dockisation. In 1859 he presented an able and comprehensive report[2] on the subject, which was afterwards referred to Sir John Hawkshaw[3] and Mr. Thomas Page.[4] Nothing came of the scheme however, and proposals were made by private individuals to construct docks at the mouth of the River Avon, with the view of accommodating vessels which could not go up to Bristol. Mr. Howard then directed his attention to plans for the improvement of the river, and an Act was obtained in 1865 for cutting off points and constructing a new entrance lock, enlarging Cumberland Basin and making a new junction lock. These improvements were completed in 1873 at a cost of about £360,000,

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[1] Minutes of Proceedings Inst. C.E., vol. xxiii. p. 481.
[2] This Report is in the Library of the Institution.
[3] Minutes of Proceedings Inst. C.E., vol. cvi. p. 321.
[4] *Ibid*, vol. xlix. p. 262.

and as a result larger vessels have been able to reach Bristol. Mr. Howard also carried out the Bathurst, the Prince's, and the Harbour Railway deep-water wharves in Bristol, besides various bridges and other works. He likewise devoted great attention to the question of floods in the Avon and Frome. Acts had been obtained by separate companies giving powers to construct docks at Avonmouth and Portishead. Avonmouth Dock[1] was opened in 1877 and Portishead Dock in 1879. The Bristol Docks were injuriously affected by the competition, and Mr. Howard, who had continued to devote great attention to dockisation, reported again on the subject in 1879.[2] Nothing came of the matter however, and Mr. Howard resigned his appointment in November, 1882. As a result of the agitation, which was carried on for a considerable time, the corporation resolved to purchase Avonmouth and Portishead Docks, the transfer being carried out in September, 1884.

Mr. Howard contributed to the British Association, at the meeting held in Bristol in 1875, a Paper on the River Avon.[3] He was recognised as an able engineer and was much respected as an upright man. He took great interest in geology, meteorology, and also in music, being a member of the Bristol Madrigal Society. Mr. Howard was elected an Associate of the Institution on the 4th of March, 1851, and was transferred to the class of Member on the 24th of April, 1866.

Commodore FERDINAND WILHELM WEGHORST LÜDERS, of the Royal Danish Navy, Superintendent of the Port of Copenhagen, died on the 29th of November, 1895, after a few weeks' illness, the cause of death being inflammation of the lungs, following an operation for cancer in the throat.

Born in the island of Funen, on the 22nd of May, 1827, Ferdinand Lüders was appointed in 1846 sub-lieutenant in the Royal Danish Navy, in which capacity he took part in 1848–50 in the first war between that country and Germany. He then attached himself to the Polytechnic School of Copenhagen, where, after three years' study, he passed in 1855 the final examination in applied mechanics. He was promoted lieutenant in that year,

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 3.
[2] This Report is in the Library of the Institution.
[3] Report of the British Association, vol. xlv. p. 175.

and acted as inspecting officer, under Commodore Tuxen, on the construction of the new graving dock at the naval dockyard in Copenhagen which was carried out by the late Mr. Alfred Giles.[1]

In 1856 Mr. Lüders came to England and entered the office of Messrs. Walker, Burges and Cooper, in Westminster, where he remained two years. During that time he was engaged on the Netherton Tunnel works,[2] and availed himself of opportunities of inspecting and studying the harbour at Dover, the docks on the Tyne and at Hull, and the construction of several of the most important lighthouses. The experience and information thus gained were of much value to him in later years, when he was frequently called upon to give evidence on marine works before parliamentary committees. In 1858 he returned to Denmark and resumed active service in the navy. Among the various duties entrusted to him was that of inspecting and purchasing timber in Germany from time to time on behalf of the Danish Navy. It was not until 1867 that he retired from the service with the honorary rank of Commander, which in 1891 was raised to that of Commodore.

On the 1st of November, 1860, Mr. Lüders was appointed Chief Engineer of the harbour of Copenhagen. He held that post until the 1st of July, 1872, when he became Superintendent of the Port (Port-Captain). For thirty-five years, therefore, he filled these important offices under the Danish Government, a sufficient testimony alike to his administrative ability and to his technical skill. His principal work was the enlargement of the harbour, which involved also several improvements rendered necessary by the development of Copenhagen and by the great increase of the commerce of Denmark. In the years immediately following 1860, when Mr. Lüders became Chief Engineer of the harbour, the sailing vessels which had hitherto carried the home trade of the country were replaced by steamers; and, subsequently, these steamers, both coasting and ocean-bound, increased rapidly in number and in tonnage. These changes had to be provided for, and, without entering into details, it may be said that there is hardly a single spot in the harbour and roadstead which, during the period in question, has not been subject to alteration and improvement, such as the extension and construction of quays, bridges and new basins, and the increase of the depth of various channels.

Meanwhile the idea of the establishment of a free port at

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[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 370.

[2] *Ibid*, vol. xix. p. 263.

Copenhagen was carried so far that in April, 1891, the preliminary works for that purpose were commenced, and the completion of the free port on the western shore of the inner roads was the last work upon which Commodore Lüders was engaged, a fitting termination of his long service. His connection with the harbour and port, occurring as it did at a period when great and important improvements were rendered absolutely necessary, may be regarded as most fortunate, not only for himself but for the country he served. Upon everything he undertook he brought to bear technical knowledge of a high order, the utmost energy and zeal, and great powers of administration.

Commodore Lüders was a Commander of the Order of the Dannebrog and had also received several foreign decorations. In 1877 he became a member of the Technical Society of Denmark and in 1892 of the Society of Danish Engineers. He was elected a Member of this Institution on the 4th of May, 1869, and was from time to time in correspondence with the office on matters of engineering interest in Denmark, as to which he was always ready to contribute valuable information.

WILLIAM NETHERSOLE, born at Kingston, Jamaica, on the 17th December, 1829, was the son of a West India merchant. He was educated at King's College, London, and at the Civil Engineering College, Putney, after which he was employed for three years on land drainage works in France. Having then obtained some experience of railway construction in this country, he was appointed Assistant Superintendent in the Army Works Corps in the Crimea, where he served during the war. He was employed on the construction of the strategical railway, much of the work being carried out under fire. The hardships of a winter in the Crimea told severely on his health, and after returning to England he was obliged to rest for a time.

In 1858 Mr. Nethersole entered the service of the Sind, Punjab and Delhi Railway Company, and was placed in charge of the construction of the Mooltan division, a length of 60 miles. From that line he was appointed in 1869 Superintending Engineer on the Indus Valley State Railway. After twenty-five years in India, he retired from the service of the Public Works Department in 1883, from which time, with the exception of some drainage and irrigation work in the island of Jamaica, he was not professionally

employed. In 1886 he married a daughter of Mr. Joseph Nash, M.D., of Box, Wilts, who survives him.

The last few years of Mr. Nethersole's life were spent at Dover. His health gradually declined, and after great suffering, which his hopeful disposition enabled him to bear cheerfully, he died on the 22nd December, 1895. His genial and sympathetic character gained him many friends. He was elected a Member on the 7th February, 1865.

CHARLES RICHARDSON, born on the 14th August, 1814, at Capenhurst Hall, near Chester, was the third son of Mr. Richard Richardson, J.P., Deputy Lieutenant for the County and Chairman of Quarter Sessions, who died when Charles was six years old. From his childhood the latter showed exceptional ability in mechanics and a natural instinct for engineering. He was educated at a private school on the outskirts of Paris and at Edinburgh, which he left in the year 1833.

At the age of nineteen Mr. Richardson was apprenticed to Isambard K. Brunel.[1] His first practical experience was obtained during the construction of the Thames Tunnel, where, as a pupil, he remained for some months while the shield was being slowly forced through the bed of the river.[2] He possessed great physical strength and activity. It was he for whom Brunel called to scramble down the St. Vincent rocks at Clifton with a message for those below when the work of getting the bar across was in progress, and from his earliest days he displayed a phenomenal taste for tasks of scarcely less danger. As a pupil he saw much work on the Great Western Railway in and around Gloucester, and at the age of twenty-three he was placed by Brunel in charge, as Resident Engineer, of the portion of the Cheltenham and Great Western Railway between Swindon and Cirencester, 18 miles in length. The nature of the ground caused much trouble, landslips occurring to an alarming extent in the banks. The details of a plan devised by Mr. Richardson to stop these landships are given in a Paper which he read before the Bristol Naturalists' Society in 1891.[3] During the construction of the Cheltenham and Great Western Railway Mr. Richardson lived for several years at Chalford, in the Stroud Valley, where there stands now an unimposing but almost unique monument of the artistic taste he brought to

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 169.
[2] *Ibid*, vol. i. (1837), p. 32, and (1840), p. 85.
[3] This Paper is in the Library of the Institution.

bear upon his work, consisting of a narrow bridge over the line where it runs through a cutting along a steep slope. The bridge was built to enable the owner of the surrounding woods to slide felled trees to the canal at the foot, and it was a necessity that the slope of the hill—rather steeper than 1 in 3—should be continued in unbroken descent. Brunel was so pleased with the appearance of the drawing that he would not allow the beauty of the proportions to be interfered with by a parapet wall, and a light iron rail only was placed on one side.

Mr. Richardson then became Resident Engineer on the Hereford, Ross and Gloucester line under Brunel. Not being satisfied that the best route had been chosen, he, with one assistant, made the survey of a new line, which was adopted by Brunel and afterwards carried out. It was while this line was in abeyance, when he lived at Ross, that he turned his attention to cricket, of which he became an enthusiastic player until late in life, and it is not generally known that he made the first cricket bat with a cane-spliced handle, and invented and made a catapult for bowling a cricket ball. His experiments at this time upon the flight of boomerangs and of carefully ground concave pebbles may also be referred to. He likewise possessed great manual dexterity and skill as a handicraftsman.

In the year 1858 Mr. Richardson was appointed Resident Engineer, still under Brunel, of the Bristol and South Wales Union Railway, a post which demanded more than ordinary power of observation to investigate the unusual currents and peculiarities of the Severn, across which the ferry was to pass, and, on Brunel's death in the year 1859, he completed the designs and finished the line as Engineer-in-Chief, in conjunction with the late Mr. R. P. Brereton. This led up to the great work of his life, viz., the Severn Tunnel, of which he was the originator and for six years the sole acting engineer, Sir John Hawkshaw[1] being the consulting engineer. In March, 1873, the sinking of the first shaft was commenced on the Welsh side of the stream. An influx of water into the heading under the Shoots, which occurred in 1879, and the consequent stoppage of the works, though due to no want of skill or foresight, and in nowise due to the subaqueous part of the undertaking, seemed to have shaken the confidence of the public in the success of the scheme; and in order to give renewed confidence, the Great Western Company thought it desirable to place Sir John Hawkshaw in the position of chief joint engineer

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 321.

with Mr. Richardson.[1] In an interesting pamphlet,[2] written by the latter for private circulation, are given in detail the particulars of his connection with this arduous undertaking, which was successfully brought to a completion and opened in 1887.

Mr. Richardson was also Engineer to the Bristol Harbour Railway, constructed by the Great Western and the Bristol and Exeter Railways jointly, from Bristol Station to the quay near Hill's dry-dock. This line had heavy works the whole way, the first portion consisting of a viaduct on arches from Bristol Station to near Redcliffe Church, then a tunnel under the churchyard and Redcliffe Hill, and a bascule bridge over the lock between Bathurst Basin and the floating harbour. This bridge can be opened or shut in about thirty seconds, and an ingenious knee-lever arrangement was introduced, which relieves the axle of the bridge when a train is passing over. Mr. Richardson likewise prepared plans for the Exe Valley Railway, which fell through at the time, but has since been carried out. While he was engaged on the Bristol and South Wales Union line he noticed the excellent quality of the bricks made out of the clay in the cutting below Patchway Tunnel and erected works there at which some 200 hands are now employed, the output being about 12,000,000 annually. Mr. Richardson took the keenest interest in all that related to the profession. In later years he prepared several Papers: an account of the Severn Tunnel was read before the Clifton Scientific Club in 1887, and in the same year he gave a Paper on Arches to the Bristol Naturalists' Society, of which he was for many years President.[3] Mr. Richardson's death, which took place on the 10th February, 1896, at the age of eighty-one, six days after a paralytic seizure, was a fitting close to a useful life. In temperament he was benevolent, genial, peaceful and contemplative, while his straightforwardness and honour were such as are rarely met with. His modest disposition prevented his being known to fame, and it was only those who were intimately acquainted with him who realised the nobility of his character. He was elected a Member on the 6th April, 1875.

GEORGE ROBERTSON, born on the 23rd July, 1830, was a son of the late Lord Benholme, and a grandson of the late Lord President Hope, Scotch judges of distinction. After being

[1] *Engineering*, vol. xxxiii. p. 48.
[2] This pamphlet is in the Library of the Institution.
[3] These Papers are in the Library of the Institution.

educated at Edinburgh Academy and the Civil Engineering College, Putney, he was articled in 1851 to the late Mr. George C. Dobson,[1] under whom he served on the Holyhead Harbour of Refuge works.[2] He then entered the office of the late Mr. James Meadows Rendel,[3] and, subsequently, acted under Mr. Rendel on the London Docks extension works. An outcome of this was a Paper entitled "An Investigation into the Theory and Practice of Hydraulic Mortar, as made on the New Works of the London Dock Company, 1856–7,"[4] which was read and discussed before the Institution in April, 1858, and obtained a Telford medal for its Author. Mr. Robertson then became associated with Sir A. M. Rendel, as Resident Engineer, in the construction of a large dry dock at Leith, and was subsequently engaged with him in designing and superintending the construction of the Albert and Edinburgh Docks and other works connected therewith at Leith. The plans for the Albert Dock were prepared in the year 1864; the dock was then immediately commenced, and was opened in July, 1869. Subsequently, also in conjunction with Sir A. M. Rendel, Mr. Robertson designed and superintended the construction of the Edinburgh Dock at Leith. His connection with Leith Docks was severed in the summer of 1883, when he gave up practice and settled in London. In the library of the Institution may be found two pamphlets he wrote on the works at Leith.[5]

In 1870 Mr. Robertson was sent out by the Secretary of State for India to examine and report on the formation of harbours in that empire. His exhaustive and valuable reports on this subject, as well as a pamphlet descriptive of Narrakal and Allippey as natural harbours of refuge on the Malabar coast,[6] are preserved in the library of the Institution.

Mr. Robertson was in failing health for some years before his death, which took place at Cambridge Gardens, North Kensington, on the 7th February, 1896. He was a Fellow of the Royal Society of Edinburgh, and in 1867–68 was President of the Royal Scottish Society of Arts, to which he contributed several Papers.[7] Mr. Robertson was a familiar figure at the Athenæum Club, of which he was for many years a member. He was elected an Associate of the Institution on the 3rd February, 1857, and was transferred to the class of Member on the 17th November, 1863.

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[1] Minutes of Proceedings Inst. C.E., vol. xli. p. 214. [2] *Ibid*, vol. xliv. p. 95.
[3] *Ibid*, vol. xvi. p. 133. [4] *Ibid*, vol. xvii. p. 410.
[5] Tracts 8vo., vols. 136 and 142. [6] *Ibid*, vol. 251.
[7] Trans. Royal Scottish Society of Arts, vol. v. p. 195; vol. vi. pp. 25, 70 and 315; and vol. vii. pp. 39, 365 and 570.

PATRICK STIRLING, born on the 29th of June, 1820, at Kilmarnock, was the son of the Rev. Robert Stirling, D.D., then one of the ministers of that parish. Dr. Stirling was well known, not only as a divine, but as a scientific man. It was he who conceived the idea of an improved air-engine, described more than fifty years ago in the Proceedings of the Institution.[1] By the persevering ingenuity of his younger brother, James, the idea was so far perfected that the engine worked well and proved an economical mode of producing power at the Dundee Foundry and also at a spinning-mill in the same town. The engine was, however, ultimately laid aside in consequence of its being found impossible to preserve the air-heating vessel from being melted or burnt, which both Ericsson and Rankine, who experimented in the same direction, found an equally insuperable difficulty.[2] From Kilmarnock Dr. Stirling went to Galston, also in Ayrshire, the charge of which parish was given to him by the Duke of Portland; and during the latter years of his life was known as the Father of the Church of Scotland.

It will be seen, therefore, that the subject of this notice inherited the mechanical genius which appears to be a strongly marked characteristic of the family. For not only did his father and uncle display ability in that direction, but his brother, James, is now Locomotive Engineer to the South Eastern Railway Company, and his second son, Matthew, occupies a similar position in the service of the Hull, Barnsley, and West Riding Junction Railway; while the eldest son, Robert, is Works Manager at Gateshead to the North Eastern Railway Company; the third son, Patrick, is Assistant Works Manager at Doncaster, and James is in the Engineer's Department of the Great Northern Railway at Nottingham.

In 1837 Patrick, then seventeen years of age, was apprenticed to his uncle, James Stirling, who was at that time Manager of the Dundee Foundry. During the six years of his apprenticeship he obtained considerable knowledge of the construction of locomotive engines. He then became foreman at a small engineering works in the Isle of Dogs. The place not agreeing with him, however, he returned after twelve months to Scotland, where he worked for three years as a journeyman in the service of Messrs. Napier & Co., of Glasgow, being paid at the rate of eighteen

[1] Minutes of Proceedings Inst. C.E., vol. iv. p. 348, and vol. xii. p. 599.
[2] *Ibid*, vol. xliv. p. 222.

shillings per week. In 1846 he entered the Hyde Park Foundry of Messrs. Neilson & Co., where he had ample opportunities of applying and developing the knowledge he had acquired at Dundee, and so well did he avail himself of them that in less than twelve months he was made foreman of the locomotive construction department. Mr. Stirling remained with Messrs. Neilson & Co. until 1851, when he was appointed Locomotive Superintendent of a short line from Bowling, on the Clyde, through Dumbarton to Balloch, on Loch Lomond, now part of the North British system. After twelve months, however, he resigned that post to join Mr. Lawrence Hill in shipbuilding at Port Glasgow. He then became Works Manager to Messrs. R. & W. Hawthorn (now Hawthorn, Leslie & Co.) of Newcastle-on-Tyne. His connection with that firm was also short, for in 1853 he was appointed to the important post of Locomotive Superintendent to the Glasgow and South Western Railway Company. Shortly afterwards the headquarters of the Locomotive Department of that line were moved to Kilmarnock, where Mr. Stirling spent the greater part of his thirteen years' service with the Company.

It is, however, with the Great Northern Railway that Patrick Stirling's name is identified. He was forty-six years of age when he was appointed, in 1866, Locomotive Superintendent to that Company; and for nearly thirty years he had charge of the shops at Doncaster. His accession to that post meant more than a similar change on any of the great lines could mean to-day. Before his time most of the engines in use on the Great Northern system were made by private firms under contracts. This was not a condition of things to satisfy a man of Mr. Stirling's ability, and he had been less than four years in charge when, in 1870, he produced the large single-driving-wheel engine with outside cylinders and a bogie at the leading end, with which his name is associated. This he described to the Institution in 1873 in the course of the discussion upon Mr. John Robinson's Paper on "Modern Locomotives,"[1] and accounts of it also appeared in *Engineering*.[2] Mr. Stirling's "8-feet singles," as they are called, were of a more powerful class than any which had preceded them and possessed special features rendering them an independent type which will no doubt become historical. In addition to their mechanical merits, they are distinguished for graceful design, and engineers from all parts of the world have described them

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. pp. 30 and 57.
[2] *Engineering*, vol. xi. p. 140, and vol. xliii. p. 471.

and chronicled their performances as typical of the best English work. The locomotives now turned out at Doncaster differ from those of 1870 only in minor modifications of detail to meet the heavier work required; and it is ample testimony to the skill and foresight of the designer that, on a line so progressive as the Great Northern, a type of engine introduced five-and-twenty years ago should still hold its own.

Mr. Stirling advocated the outside cylinder type long after it had been abandoned by most locomotive engineers for the express service in this country, although he from time to time built some engines with inside cylinders. When hard running was required, he always suggested the use of outside cylinder engines, and certainly the manner in which his performed their duty fully warranted his belief in them. The large driving-wheels give ample adhesion for the work to be done; they are heavily-loaded —carrying 17 tons—but, with steel rails and a good permanent way, this load has not proved excessive. The adoption of the Gresham steam sanding apparatus removes any difficulty at starting, and once the train is in motion no further trouble is experienced. At very high speeds there has been little wear and tear of these engines; in fact, they have proved economical in every way. The straight-topped boiler without steam-dome was another characteristic of Mr. Stirling's locomotive. He did not believe in the use of the steam-dome and he had no trouble from priming, which was probably a result of the ample space left between the tubes. Another feature was the method of staying the crown of the fire-box, which was coupled direct to the top of the boiler. It may be added that he was a strenuous opponent of the compound system in locomotives.[1]

Only in August last Mr. Stirling's engines took a Scotch express over the 188 miles between London and York in 188 minutes. When a few years back the superintendent of the line informed him, not without hesitation, that it was proposed to accelerate still more an already fast and heavy express, Mr. Stirling replied, "There is no need to consult me. As long as you don't time the train above 60 miles an hour, including stoppages, the engines will be all right." During the last thirty years the locomotive department has increased in extent and importance with the growing requirements of the Company and of the public. The ground now covered by the works at Doncaster is more than 30 acres, while upwards of 8,500 men were employed under Mr. Stirling's imme-

[1] *Engineering*, vol. lx. p. 612.

diate supervision. Only a man of exceptional vital powers would have continued to carry out such arduous duties so late in life, but he lived for his work, and the daily routine had become a habit which could not have been broken without a severe shock. Beyond perhaps a love of reading and of flowers he had no hobby apart from his work, although latterly he took considerable interest in the proceedings of the town Tennis Club, of which he was President. But in the shops and on the metals Mr. Stirling was at home. He would wander over the latter in the most reckless fashion, engrossed in thought, as though the engines he had built could not dare to hurt him, and more than once he came perilously near being run over. As an illustration of the good feeling existing between him and his men, it may be mentioned that they erected and presented to the town a handsome drinking fountain, to commemorate his seventieth birthday, and "to mark the respect and esteem in which he is held by them." If a demand were made for a temporary reduction in the amount of wages paid, Mr. Stirling took care that the burden which the men had to bear should be as light as possible. He invariably had recourse to short time all round as a means of reducing expenses, and except under necessity men were never discharged. While carrying out his duty towards his directors with the utmost fidelity and zeal, Mr. Stirling never refused to listen to an honest appeal for justice from one of his men. In private life he was a charming companion, but in business and public matters he was laconic and reserved to a degree, and he was altogether a man whose friendship was most valued by those who knew him best.

Mr. Stirling died at his residence in Doncaster on the 11th November, 1895, the cause of death being pneumonia complicated by heart disease, from which he had suffered for some years. He was elected a Member of the Institution on the 28th May, 1878, but his devotion to his work and his retiring disposition prevented him from taking any prominent part in its proceedings. Mr. Stirling was one of the original Members of the Institution of Engineers and Shipbuilders in Scotland. In 1877 he was placed on the Commission of the Peace for the borough of Doncaster.

GEORGE AMBROSE WALLIS, born on the 25th November, 1840, was the eldest son of Mr. A. G. Wallis, of Walham Green, London. At sixteen years of age he entered the service of Messrs. John Aird & Sons, the contractors, by whom his father was

employed. After being engaged on alterations and additions to the Ipswich Waterworks and on the construction of the South Staffordshire Waterworks, by which an extensive district is supplied from Lichfield, he was personally recommended by Mr. John Aird to the late Mr. J. R. McClean[1] for the post of Resident Engineer on the Eastbourne Waterworks.

Eastbourne in 1860, when Mr. Wallis first became connected with it, was a quiet, unpretentious little town of some 5,000 inhabitants. As agent to the Compton Place Estate of the Cavendish family, he took a prominent part in planning and directing the extensive improvements—carried out, at a great cost, on the initiative of the late Duke of Devonshire[2]—which have done so much to render the town a watering-place of first-class reputation. The land now forming the Devonshire Park was at one time an allotment garden below high-water mark; Mr. Wallis, quick to perceive that it might be turned to good account, had it levelled, laid out and planted, transforming it into a pleasant and sheltered resort. He designed the Devonshire Baths, which are below the sea-level and can be filled or emptied by the same pipe, according as the tide is high or low. The extension of the parade from the Wish Tower to Holywell, involving the construction of a sea-wall, and the Duke's Drive, a fine carriage way with an even gradient to Beachy Head, were also carried out by Mr. Wallis; and a few years ago he extended the sea-wall and promenade from the Royal Parade to the east of the Redoubt. Many of the principal streets in the town were laid out and the houses built by the firm he established.

Three years after he had settled in Eastbourne, Mr. Wallis was appointed—in 1863—surveyor to the Local Board, which post he held till 1866. During that period the system of drainage, designed by Messrs. McClean and Stileman,[3] was commenced, the cost of the works being borne by the late Duke of Devonshire. In 1870 Mr. Wallis became Engineer to the Eastbourne Waterworks Company, for which he designed and constructed reservoirs, wells, an engine-house and mains, at a cost of £40,000. Alive to the importance of securing for the villages around Eastbourne a clean bill of health, he extended the Company's mains to Willingdon and Polegate in one direction and to Norway Bridge in the other. He also carried out during recent years other large extensions rendered necessary by the growing requirements of the

[1] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 287.
[2] *Ibid*, vol. cvii. p. 393. [3] *Ibid*, vol. xcviii. p. 401.

town, and he continued to hold the appointment of Engineer and General Manager until his death.

On the incorporation of the borough in 1883, Mr. Wallis was elected first mayor, an office which he served for two years with great credit. As a mark of public appreciation his portrait was presented to the borough and was hung in the Town Hall. In 1885 he unsuccessfully contested Eastbourne in the Liberal interest against Admiral Field. About this time he was called upon by the Servian Government to report on the drainage of Belgrade, for which he was decorated with the order of Takovo. He was a promoter of the Newhaven Portland Cement Company, and was connected with many other enterprises. He was on the Commission of the Peace for the County of Sussex, but rarely sat on the Borough Bench.

For some years Mr. Wallis had not enjoyed robust health, but his active temperament prevented him from seeking relief from the cares which his many responsibilities entailed and he remained at work until the last. A chill, caught early in December, 1895, told severely on his undermined constitution; and he expired on the 20th of that month at the comparatively early age of fifty-five. Of Mr. Wallis' work as an engineer and the part he took in the improvement of Eastbourne, with which his career was identified, much has been said. He was well known, however, beyond Eastbourne, and his services as a consulting engineer were frequently in request. It remains only to record that in character he was kind, generous and considerate, and that, while he was possessed of a determined will, he knew how to secure the carrying out of his wishes without wounding the susceptibilities of others. In Eastbourne he was much esteemed and respected, and his death is a great loss to the town with which he was so long and so intimately connected. Mr. Wallis was elected an Associate of the Institution on the 5th December, 1865, and was transferred to the class of Member on the 8th May, 1877.

JOHN YOUNG, born on the 27th March, 1826, was educated at the Perth Academy. He then became a pupil of his father, the late Mr. James Young, who, in partnership with Mr. Alexander Mitchell, was practising as an engineer and architect in Perth. After gaining some experience of railway construction under Messrs. Locke and Errington, John Young commenced business

on his own account in Perth in the year 1855, and during the next forty years was connected with many important works. The first of these was the drainage of the city of Perth, which he carried out between 1862 and 1867. On account of the level of the town being in many places only a few feet above the normal level of the river, the works presented considerable difficulties, which Mr. Young overcame with great judgment and skill. He was also responsible for the drainage of Selkirk, Crieff, Blairgowrie, and Newport (Fife).

Between the years 1877 and 1880 Mr. Young carried out, in conjunction with the late Mr. J. F. La Trobe Bateman,[1] an extension of the Perth Waterworks. He was also engaged on works for the water-supply of Crieff and of Dunblane. In addition to drainage and water-supply, he had some experience of railway works, having prepared plans for a narrow-gauge line from Alyth to Braemar and acted as engineer on the construction of the Crieff and Comrie Railway, an extension of the Caledonian system. He was also the architect of several public buildings in Perth and engineer to the Perth and District Tramways, recently completed and opened.

Mr. Young died on the 2nd December, 1895, after a short illness, death being attributed to a chill. In social life he was very popular. He was the author of a little volume of songs and poems and had some skill as a musician. Mr. Young was a town councillor and magistrate of Perth, and an enthusiastic Freemason. He was elected a Member on the 1st December, 1891.

RICHARD FREDERIC FITZ-EDMUND HAYES, M.A., born at 25, Mountjoy Square, Dublin, on the 10th May, 1855, was the fourth son of the Hon. Mr. Justice Hayes, a Judge of the Queen's Bench Division, Ireland. He was educated at the Royal School of Dungannon and afterwards at Londonderry, but owing to ill-health was obliged to leave and for some considerable time was an invalid. On his restoration to health, he passed first in an examination of candidates for the Straits Settlements Civil Service. On presenting himself however for physical examination he was disqualified; this was a heavy blow, but he resolved to pursue the Dublin University course, which he had already commenced, and to become a civil engineer. His mathematical abilities were brilliant, and he carried off many prizes as well as a gold medal

[1] Minutes of Proceedings Inst. C.E., vol. xcvii. p. 392.

and the Senior Moderatorship in experimental science and mathematics. From the engineering school of Trinity College, Dublin, he obtained not only the regular diploma granted by the University, but special certificates in mineralogy, chemistry, geology and mining. In May, 1881, he was articled to Mr. Shelford, who subsequently entrusted him with the superintendence, under the Resident Engineer, of the construction of part of the Hull and Barnsley Railway.

Mr. Hayes was then employed for two years by the Lancashire and Yorkshire Railway Company in preparing contract plans for the Hindley and Pendleton line, and in making drawings for iron and masonry bridges, roofs and station buildings. In 1886 and 1887 he was engaged in Co. Galway in charge of a number of small harbour and bridge works, all of which were executed to the satisfaction of the Board of Public Works. He then entered the office of Messrs. James Livesey and Son, whom he left, however, for the purpose of constructing a railway in Mexico, and afterwards undertook a contract for the erection of station buildings in the same country. For some time he had been busy in the introduction of a preparation of pine wood into London, which is expected to be useful for many purposes, but in the midst of health and activity he was struck down by diphtheria. Mr. Hayes died in London on the 18th of December, 1895. He was elected an Associate Member on the 27th May, 1884.

EDWARD WILTHEW JACKSON, born in London in September, 1838, was the eldest son of the late Mr. Thomas Jackson, who, in his day, was known as an enterprising contractor. Edward early in life entered his father's office, and from 1856 until January, 1863, was engaged under him on the construction of the Smyrna-Aidin Railway in Asiatic Turkey. He then acted for eighteen months as superintendent of the works for the extension of the Keyham Dockyard, which were carried out under the charge of the late Mr. Richard Townshend.[1]

In the autumn of 1864 Mr. Jackson proceeded to Mexico, in which country he spent the remainder of his life. He was first employed for nine years as Assistant Agent to the late Mr. George B. Crawley, the contractor, on the construction and equipment of the Mexican Railway, a line 263 miles in length from the city of

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 494.

Mexico to the sea-port of Vera Cruz, with a branch from the latter to Jalapa, a distance of 70 miles. In December, 1873, he became Assistant Manager, and in September, 1875, was promoted to the post of Manager, to the Mexican Railway Company. Mr. Jackson performed the duties of that office for ten years, when he resigned in order to accept the appointment of General Manager to the Mexican Central Railway, in September, 1885. This was an important post, for he was responsible for the administration and working of nearly 1,900 miles of railway, of which 1,224 miles were main line.

In December, 1894, Mr. Jackson transferred his services to the Interoceanic Railway of Mexico (Acapulco to Vera Cruz) as General Manager. This was apparently a less onerous position, as there were only some 530 miles in operation, but disaster seemed to follow this step. Although he surrounded himself with tried subordinates, unforeseen difficulties arose and unpreventable accidents on the line added to his distress. The sudden death of his wife was a shock from which he could not recover, although he threw himself into work with closer attention than ever. For some years he had suffered from liver complaint, but his death, which took place suddenly on the 2nd of September, 1895, was attributed to heart disease. Mr. Jackson's services were greatly appreciated in Mexico, where his strong personality evoked admiration and esteem. He was elected an Associate Member on the 7th of December, 1880.

EDWARD WORRELL JARVIS was born at Charlottetown, Prince Edward's Island, Canada, on the 26th January, 1846. On the death of his father, who was Chief Justice of the Island, he came to England to be educated. After serving a pupilage of three years to Mr. W. M. Brydone, he returned to Canada in 1868, when he was employed on the Intercolonial Railway in Nova Scotia and New Brunswick. From 1871 to 1873 he carried out surveys, some across the Rocky Mountains, for the Canadian Pacific Railway. In the autumn of 1874 he was selected to make a preliminary exploration of the Smoky River Pass of the Rocky Mountains. A full account of this exploration, which was of a dangerous character, will be found in the official Report on Surveys, Canadian Pacific Railway, 1877.[1]

[1] This Report is in the Library of the Institution.

On his return to Winnipeg in 1875 Mr. Jarvis entered into business as a lumber merchant. In 1880–83 he built the Louise and Broadway bridges over the Red River and the Main Street bridge over the Assiniboine River in the City of Winnipeg. He was in command of the Winnipeg Field Battery of the Canadian artillery, served with it in the Riel rebellion of 1885 and was mentioned in despatches. He then received an appointment as Superintendent in the North-West Mounted Police, which he held until his death at Calgary, Alberta, on the 26th November, 1894.

JOSEPH GODBER KNIGHTON, born on the 14th June, 1851, was the son of Mr. William Knighton, of Staveley. After serving articles to the late Mr. Charles Markham,[1] he was appointed in 1873 Assistant Manager, under that gentleman, of the foundries, blast furnaces, and engineering department of the Staveley Coal and Iron Company. In 1887 he became Foundry Manager, which position he held until his death at Barrow Hill, near Chesterfield, on the 5th of August, 1895. Mr. Knighton's charge of these important works, which he held first under Mr. Markham, and subsequently under Mr. George Bond, the recently deceased General Manager, was fulfilled with energy and zeal, and in him the workmen of the district have lost a good friend. For twenty years he served as a lieutenant in the local Volunteer corps. He was also a Freemason and an able musician, playing the violin with great skill. Mr. Knighton was elected an Associate Member on the 7th April, 1891.

JAMES HENRY CORNWALL LANGDON, born at St. Heliers, Jersey, on the 5th February, 1853, was articled in 1868 to Mr. A. B. Campion, Borough Surveyor of Neath, Glamorganshire, whom he assisted in the design and construction of the drainage of that town. He then served for seven years on the engineering staff of the Midland Railway, as an assistant in the southern division. In 1877 Mr. Langdon proceeded to South Australia, and in March of the following year was appointed City Surveyor and Engineer of Adelaide, which post he held until his death. He designed and erected a weir over the River Torrens, turning the dry bed of the river into a permanent lake two miles long; designed

[1] Minutes of Proceedings Inst. C.E., vol. xcv. p. 377.

one and built two bridges over the same river; and designed and supervised the construction of many of the Corporation buildings. At the time of the heavy floods in the Torrens in 1890, when the weir was threatened with destruction owing to the large number of huge gum-trees brought down by the waters, Mr. Langdon was directing the removal of the heavy masses of timber, when he was carried over the weir amongst a large accumulation of logs, receiving an injury to his spine which resulted in paralysis. He remained in office until January, 1895, when he succumbed to an acute attack of pneumonia. Mr. Langdon was elected an Associate Member on the 7th February, 1882.

RICHARD ALOYSIUS LAVERTINE, B.E., eldest son of Mr. John Lavertine, of Limerick, was born on the 7th of October, 1853, and was educated at the Queen's University, Dublin (now the Royal University of Ireland), where, in 1876, he obtained the degree of Bachelor in Engineering. With characteristic energy he made the best use of the long vacations during his University career by gaining practical knowledge of the profession in the office of Mr. Maurice Hennessy, of Limerick; by which means he usefully supplemented his theoretical studies. In January, 1877, he became an Assistant to the late Mr. William Barrington,[1] for whom he acted from November, 1878, as Resident Engineer on the construction of the Limerick and Kerry Railway.

That line was completed in May, 1880, and in the following October Mr. Lavertine was appointed Government Surveyor for the district of Pretoria, Transvaal. Shortly after his arrival, war broke out between the Boers and the English, and Mr. Lavertine served for three months as a volunteer in the Pretoria Carabineers, his horse being shot under him on one occasion when he narrowly escaped with his life. When the Transvaal was handed over to the Boers at the conclusion of the war, he was appointed Government Surveyor to the Republic. In that capacity he conducted between February, 1882, and May, 1884, a flying survey of Stellaland (Bechuanaland), 10,000 square miles in extent, and laid out the town of Vryburg; and, during the two following years, he was continuously employed on extensive surveys for the Transvaal Government.

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[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 341.

Since August, 1886, Mr. Lavertine was engaged privately in the Transvaal, where he rapidly acquired an extensive practice on survey work and in mining operations. Among the numerous mining companies for which he carried out works from time to time may be mentioned the Revolver, the Mount Morgan, the Figaro, the Scotsman, the Sheba, the De Kapp Gold-Fields and the Midas. He also acted as Engineer and Manager of the Clewer Estate, Lydenburg, an extensive mining property, and made a survey of the town of Barberton for the Transvaal Government. In 1895 Mr. Lavertine suffered a severe attack of rheumatic fever, which so seriously affected his heart as to leave slight hope of recovery. Accompanied by his wife he was returning home, when he died on board the Union Company's steamer "Norman" on the 12th of August, 1895. Mr. Lavertine was possessed of a thorough knowledge of the Transvaal, where he was much respected as an engineer of ability and integrity. He was elected an Associate Member on the 7th of April, 1891.

ALFREDO HENRIQUE PACHECO, born on the 2nd February, 1855, was educated at the Polytechnic School of Rio de Janeiro, where he obtained a diploma as a Civil Engineer. In 1873 he entered the Public Works Department of Brazil, in which service he remained until his death at Rio de Janeiro on the 14th February, 1895. From 1877 to 1883 Mr. Pacheco assisted in carrying out the works for the water-supply of Rio de Janeiro, and in 1886 he was appointed one of the Government Engineers to fiscalize the Improvements Company of that city. He was subsequently placed in charge of one of the sections of the Public Works Department. Mr. Pacheco was elected an Associate Member on the 3rd December, 1889.

WILLIAM POLLOCK, born on the 27th July, 1864, was educated at Glasgow University. He then served a pupilage of five years, first to Mr. Mortimer Evans, and subsequently to Mr. Thomas D. Weir, and in 1886–87 he was employed by Mr. Weir on the construction of the Keppel Pier and on work in connection with the Glasgow Central Railway. In 1888 he entered the service of Messrs. Johnstone and Rankine, of Glasgow, and remained with them as principal assistant till the summer of 1893. During

that period he was engaged on work for the Glasgow Corporation Tramways and the Highland Railway Company; the construction of private railways; and the valuation of extensive colliery and other undertakings. In May, 1893, Mr. Pollock entered the service of Mr. Murdoch Paterson, under whom he was engaged on the extension of the Highland Railway from Strome Ferry to the Kyle of Lochalsh, a rugged and difficult country, and subsequently acted as Resident Engineer on the construction of the western section of the line, including the deep-water pier at Kyle.

In 1894, however, Mr. Pollock's health failed, and it was apparent that he was suffering from consumption. He was taken to Edinburgh, where he died on the 17th October, 1895. Mr. Pollock was an excellent draughtsman and very correct in his work, while all who were brought into contact with him appreciated his kindly disposition. He was elected an Associate Member on the 1st April, 1890.

EDWARD QUICK, born at Lewisham on the 21st of September, 1857, was the fourth son of the late Mr. Joseph Quick.[1] After being educated at Clifton College, he entered the office of Messrs. Quick & Son in Westminster as a pupil in 1875. During the four years of his pupilage he was employed, in addition to office work, on extensions of the Portsmouth, Kenley, and Staveley Waterworks. From 1879 he remained with the firm as an assistant, being first engaged on the Woking Water and Gasworks. He was then upwards of two years in Vienna on the staff employed by the firm in preparing the plans for the new waterworks of that city. On returning to England Mr. Quick took an active part in the initiation and design of several lines of tramway, both in the metropolis and in the provinces, notably at Exeter, Plymouth, and in the neighbourhood of Manchester. He subsequently became junior partner in the firm and, on the death of his father in March, 1894, continued to carry on the business with his eldest brother, Mr. Joseph Quick.

In addition to the works already referred to, Mr. Edward Quick inspected and reported on the water-supply of Malaga, on tramways in Holland, and on light railways in Italy. His knowledge of foreign languages and mathematical skill, in addition to the experience he had gained abroad, rendered his services extremely valuable to the firm. Mr. Quick died at his residence, Telford

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 383.

Avenue, Streatham Hill, on the 11th of November, 1895, from typhoid fever. He was elected an Associate Member on the 5th of December, 1882, and when at home was a regular attendant at the meetings of the Institution.

CHARLES LEOPOL STRAPP was born on the 15th of October, 1867, at Lemberg, Galicia, where his father, Mr. William Strapp, was engaged at that time on railway construction for the Austrian Government as representative of the late Mr. Thomas Brassey.[1] Leopol was educated at Tonbridge School and then went through a course of two years' study at the Crystal Palace School of Practical Engineering, under Mr. J. W. Wilson. In November, 1887, he obtained an appointment as an Assistant on the Contractor's staff of the Manchester Ship Canal and was posted to No. 3 District, under Mr. A. G. Luke. He was thus engaged for more than three years, generally undertaking work which required personal strength and activity, such as the construction of all kinds of heavy timberwork in cofferdams and viaducts, both in the river and on land. On one occasion he rescued the crew of a boat which had been capsized, at a time when none of the shoremen would venture on the river.

From May, 1891, to September, 1892, Mr. Strapp was employed by Messrs. Eckersley, Godfrey & Liddlelow on the construction of the Athens-Larissa Railway. He was then engaged in Turkey for a French Company in preparing surveys for a railway from Salonika to Dédéagatch on the Gulf of Enos, and was subsequently in charge of a section of the line. Mr. Strapp returned to England at the beginning of 1895 and in the following July proceeded to Egypt for the Société Anonyme du Béhéra. His career was, however, prematurely cut short, for after only a few months' residence in Egypt, he was attacked by peritonitis at Alexandria. An operation was followed by blood-poisoning, which proved fatal on the 5th of November, 1895. Mr. Strapp was an exceptionally fine, well-built man, and fond of all sports. He served for some time as a lieutenant in the 2nd V. B. Queen's Royal West Surrey Regiment. He was much esteemed for his energy and honesty of purpose, which caused him to be feared by some of the doubtful characters who worked under him in Turkey and Egypt. He was elected an Associate Member on the 5th of December, 1893.

[1] Minutes of Proceedings Inst. C.E., vol. xxxiii. p. 246.

MICHAEL NICHOLSON THOMSON, born on the 13th of October, 1864, was a son of the late Mr. Alexander Thomson, of Glasgow, an architect better known as "Greek Thomson," and a great-grandson of the late Mr. Peter Nicholson, who wrote several works on architecture, building and construction,[1] and who in 1844 took part in a discussion at the Institution on the scaffolding used in erecting the Nelson Column in Trafalgar Square.[2] Michael, after being educated at the High School, Glasgow, was apprenticed for five years, in October, 1879, to the late Sir William McOnie, of that city, under whom he acquired a practical knowledge of the business of an engineer and millwright. In April, 1885, in order that he might gain still further experience, he was articled to Messrs. Niven and Haddin, of Glasgow, with whom he remained until January, 1888.

Mr. Thomson was then engaged for six months in the office of Messrs. Thomson and Sandilands, architects, of Glasgow, after which he entered in July, 1888, the service of Messrs. Matheson & Co., of Lombard Street, London. By that firm he was employed in preparing plans, specifications and estimates for various engineering works. Mr. Thomson remained with Messrs. Matheson & Co. until his death, which took place on the 15th of October, 1895, at Fulham, after a short illness, the cause being attributed to blood poisoning. He was a man of considerable ability, well-informed and of studious habits, was much esteemed by his employers, and had every prospect of doing well in the profession had his life been spared. He was elected an Associate Member on the 5th of May, 1891.

THOMAS SAMUEL WEEKS was born on the 7th April, 1838, and was educated at Torquay. After being for some time in the office of Mr. Edward Appleton, of that town, he was employed by Messrs. J. T. and W. Harvey to superintend several building contracts, including the stations of the Dartmouth and Torbay Railway. He also acted in a similar capacity on the construction, for the War Department, of the Scrasedon Fort near Plymouth.

In 1864 Mr. Weeks was appointed Assistant to the Surveyor of the Torquay Local Board, and in December, 1877, he became Water Superintendent, which post he held until his death. He

[1] Many, if not all, of Mr. Peter Nicholson's works are in the Library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. iii. p. 206.

was associated with the late Mr. William Froude in the then novel operation of scraping the inside of the supply main which had become incrusted with rust. At the suggestion of the late Mr. J. G. Appold, a piston, carrying knives to dislodge the rust, was propelled through the pipe by the pressure in the main, the rust being removed by the flow of water.[1] Mr. Weeks was also engaged on the construction of the Kennick impounding reservoir at the gathering ground of the Torquay waterworks, and he was mainly instrumental in bringing into use in the town the Deacon system of checking waste. Mr. Weeks died at Torquay on the 14th December, 1895, from dilatation of the heart. As an engineer he was painstaking and reliable, while in disposition he was retiring and thoughtful. He was elected an Associate Member on the 6th March, 1883.

WILLIAM ALEXANDER ADAMS, son of the late Mr. William Bridges Adams, was born at Quintero, Chili, on the 26th August, 1821. In 1826 he came to London and at the age of fifteen was placed in the carriage-works belonging to his father and uncle in Drury Lane. In 1843 the Fairfield Works, Bow, were erected by them, and he was taken into partnership. Mr. Adams severed that connection in 1846, when he became manager to Messrs. Fox, Henderson and Co., of the London Works, Birmingham. In the latter part of that year, however, he set up in business with Mr. George Allcock. That partnership was dissolved in 1850, when Mr. Adams started on his own account. In the same year he presented to the Institution of Mechanical Engineers, of which he was a Member, two Papers "On Railway Carriage and Wagon Springs" and two dealing with railway carrying stock; and in 1852 he contributed to the same Institution a further Paper "On Improvements in the Construction and Materials of Railway Wagons." Mr. Adams' knowledge of the mechanical construction of railway wagons, coupled with energy and perseverance, made his business very successful. In 1853 he formed the Midland Wagon Company, and ten years later he and his then partner, Mr. Henry Griffith, sold their business to this Company, on the board of which he retained a seat. About that time he became a director of Muntz's Metal Company. In 1874 he introduced into the United States the purchase lease system of letting railway wagons, and in the following year he formed the Union Rolling Stock Company for the purpose of financing wagons on that

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 397.

system in the States. In 1876 Mr. Adams presented to this Institution a Paper entitled "Railway Rolling Stock Capacity, in relation to the Dead Weight of Vehicles,"[1] which was read and discussed in conjunction with a communication "On the Construction of Railway Wagons, with special reference to Economy in Dead Weight"[2] by the late Mr. W. R. Browne.

Mr. Adams died at Gaines, Herefordshire, on the 31st January, 1896, at the age of seventy-four. He was a keen sportsman, and wrote a book entitled "Twenty-six Years' Reminiscences of Scotch Grouse Moors" and a pamphlet on "Bores and Loads for Sporting Guns for British Game Shooting," both of which were published by *The Field* office. Mr. Adams was for some years a director of the Birmingham Joint Stock Bank and a Justice of the Peace and Deputy Lieutenant for the County of Hereford. He was elected an Associate on the 10th January, 1865.

Colonel FRANCIS DAVID MILLETT BROWN, V.C., of the Indian Staff Corps, who died at Sandown, Isle of Wight, on the 21st of November, 1895, from pneumonia caused by a chill, was the second son of the late Mr. G. F. Brown of the Bengal Civil Service. He was born on the 7th of August, 1837, entered the army in 1855, and saw much active service during the Indian Mutiny with his regiment, the 1st European Bengal Fusiliers. In the subsequent operations in Oudh he won the Victoria Cross for great gallantry in rescuing a wounded soldier under heavy fire. After serving in the Umbeyla Frontier Campaign in 1863, he joined the Indian Public Works Department in 1865 by passing through the Thomason Civil Engineering College, Roorkee, of which Institution he was shortly after appointed one of the Assistant Principals. From 1867 to 1890 he was employed in executive work, serving as Assistant, Executive and Superintending Engineer in the "Building and Roads" Branch of the Public Works Department in the North-West Provinces and Oudh. He took a keen interest in road and bridge work and especially in the construction of the cart road from the foot of the hills to the cantonment of Ranikhet—about 30 miles in length—through very difficult country liable to heavy slips.

After a short furlough in 1890 Colonel Brown went back to India as Principal of the Thomason Civil Engineering College, in which

[1] Minutes of Proceedings Inst. C.E., vol. xlvi. p. 100.
[2] *Ibid*, vol. xlvi. p. 81.

he had been educated. He finally returned to England in August, 1892, after an honourable service of thirty-seven years, of which all but ten years had been spent in Civil Engineering. From that time he resided at Tiverton, Devon, where he took an active interest in Church work, forming a battalion of the Church Lads' Brigade, of which he became the Commandant. Colonel Brown was buried at Winchester cemetery, the first part of the service being held in the Cathedral, where the colours of his old regiment hang. He will long be remembered by those who knew him as a brave soldier and a kind and gentle man. He was elected an Associate on the 3rd of May, 1870.

JOHN THEWLIS JOHNSON, born on the 22nd March, 1836, was the eldest son of Mr. Thomas F. Johnson, of Manchester. After being for some time in his father's cotton mill, he became in 1860 a partner in the firm of Messrs. Richard Johnson and Nephew, of the Bradford Ironworks, Manchester. The business of this firm, of which Mr. Thewlis Johnson ultimately became head, was the manufacture of wire for telegraph, fencing, and other purposes, and with that industry he was identified during a long and successful career. He took a lively interest in all matters relating to the trade of Manchester and the district, and was for many years a member of the Chamber of Commerce of that city. In 1892 he was elected Vice-President and in the following year President of that Chamber. Mr. Johnson was a Justice of the Peace for the county of Derby, a director of Nettlefolds, a member of the Iron Trades' Association and a Vice-President of the Manchester Geographical Society. He died at his country residence, Ambergate, Derbyshire, on the 15th January, 1896. Mr. Johnson was elected an Associate on the 4th December, 1866.

CHARLES THOMAS LUCAS, son of Mr. James Jonathan Hughes Delight Lucas, builder, of Quaker descent, was born in London on the 26th of October, 1820, and died at Warnham Court, near Horsham, from general decay, on the 4th of December, 1895, in his seventy-sixth year. He was married in 1850 to Charlotte Emma Tiffin and had a family of two daughters and five sons, of whom three sons survive him.

Mr. Lucas was articled to Mr. Stokes, builder, of London, and his first responsible work was, as agent for Mr. S. M. Peto (after-

wards Sir Morton Peto),[1] the superintendence of the Norwich and Brandon Railway. It was to this start, and to Mr. Peto's interest in him, that he always attributed his success in life. His business career extended over more than half a century and was characterised from its earliest days by a tenacity of purpose, a strength of will and a power of wielding great authority which made him one of the foremost men of the nineteenth century, rich as it has been in men of mark who followed the same pursuit. He was distinguished for his straightforward manner and for the honourable way in which he entered into and carried out all his engagements, whether profitable or not; and he earned for himself a reputation for probity, unswerving integrity and keen business ability which stood him in good stead to the end of his life. To use the words of one of his friends, "No one who knew him, however slightly, could fail to be impressed with the nobility of his character. He had such a kindly, pleasant manner that all looked upon him as a warm friend." It was ever a source of great pride to him to relate how he had been associated in many large undertakings with such well-known men as Mr. Thomas Brassey, Sir Morton Peto, Sir John Kelk, Sir Charles Barry, Messrs. Waring, Mr. George Wythes, Mr. G. P. Bidder and many other engineers, architects and contractors.

Mr. Lucas commenced business on his own account as a builder and contractor at Norwich, and after a short time was joined by his brother, now Sir Thomas Lucas, with whom he founded the firm of Lucas Brothers, and remained in partnership until his death, a period of more than fifty-three years. Their well-known works at Lowestoft gave employment to vast numbers of workmen and were the scene of the production of enormous quantities of materials, which were utilized in the various works carried out by the firm. The Royal and Harbour Hotels, the Esplanade, the Marine Parade, St. John's Church, Kirkley Cliff, all at Lowestoft, and the water-works there and at Norwich and Yarmouth, were among their early successful undertakings. These were followed by many works in Norfolk and Suffolk, including, among others, Somerleyton Hall, Henham Hall, Sennowe Hall and Rendlesham Hall. The business grew to such large proportions that a move was made to London, where extensive works were established in the Belvedere Road, Lambeth, and for many years the firm was well known as contractors for large undertakings, amongst which may be mentioned Cannon Street Hotel and Station, Charing Cross

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 400.

Hotel and Station, the Langham Hotel, De Keyser's Hotel, the Star and Garter Hotel at Richmond, and the London Bridge Terminus Hotel; also the Royal Italian Opera House, which was justly regarded as a great achievement, having been rebuilt and opened within seven months after it was burned down. The firm also rebuilt Cliveden for the then Marquis of Westminster, and constructed the Royal Albert Hall, St. James's Hall, the Floral Hall at Covent Garden, York Railway Station and Hotel, the East Norfolk Railway and a large portion of the Great Eastern Railway, the South Kensington Exhibitions of 1867 and 1871, the Alexandra Palace, the City Terminus and Hotel at Liverpool Street, the Charterhouse School at Godalming, Normanhurst (the seat of Lord Brassey), the Junior Carlton Club, the Whitehall Club, Westminster Chambers, the Buckingham Palace Hotel, works for the South-Eastern Railway, and works at St. Pancras Station for the Midland Railway Company. One of their most satisfactory undertakings in its good results was the housing of the troops in the Crimea, for which they received the special thanks of the Government. They also carried out works at Woolwich Arsenal, and formed the whole of the camps and barracks at Gosport and at Colchester, partly those at Shorncliffe and at Aldershot, and the School of Gunnery at Shoeburyness, besides a number of other scarcely less important works. They also constructed, in conjunction with Messrs. Kelk and Waring, the Metropolian District Railway and many of its branches, and with the then Mr. Kelk, the International Exhibition of 1862.

In 1874 arrangements were made for Mr. John Aird to join the firm, which was thenceforward known as Lucas and Aird. The business now assumed even greater proportions, and the firm became one of the largest employers of labour in the country. Among the works carried out may be mentioned the Hull and Barnsley Railway, the Kettering and Manton Railway (with the viaduct across the Welland Valley) for the Midland Railway Company, works for the London Chatham and Dover, London and South Western, North Eastern, Midland, Great Western, and South Eastern Railway Companies, Blackfriars Railway Bridge, Tottenham and Forest Gate Railway, extensions of the East and West India, St. Katharine's, and Surrey Commercial Docks, the Royal Albert Docks, the Tilbury Docks, Hodbarrow Sea Wall, the West Highland Railway, Ardrossan Harbour, and the extensive dock-works now in progress at Southampton. Mr. Lucas and his brother were also members of the firm of Messrs. John Aird and Sons, contractors for many undertakings for Gas and Water Companies, both at home and abroad. It should

also be mentioned that, during the last Egyptian campaign, the firm of Lucas and Aird placed their resources at the disposal of the Government for the construction of the railway from Suakim to Berber, and vast quantities of plant and stores were forwarded to Suakim accompanied by a numerous and efficient staff, although the close of the war led to the abandonment of the undertaking.

Mr. Lucas was for thirty-one years an Associate of the Institution, having been elected on the 6th of December, 1864. He showed a keen interest in all that appertained to its welfare and especially in the Benevolent Fund, on the Committee of which he served from time to time. He was a Lieut.-Colonel of the Engineer and Railway Volunteer Staff Corps and was associated with many of the leading public bodies in the City of London.

Mr. Lucas was the owner of the beautiful estate of Warnham Court in Sussex, and in his hours of relaxation took great pride in his gardens and in the rearing of cattle, sheep and horses, his various herds being well known in the agricultural world. He was devotedly attached to children and to music, and the death of his two daughters and of his youngest son, so near to that of his wife, was a profound grief to him; they were sorrows from which he never recovered, and there is little doubt that the commencement of the decline in his health may be traced to that date. He was several times offered a seat in Parliament without opposition, but he always considered that the attention he was obliged to devote to his business and to the large undertakings connected with it precluded him from accepting the responsibilities and demands upon his time inseparable from a parliamentary life. He was, however, frequently consulted by Lord Beaconsfield and Mr. W. H. Smith upon the labour question, which he thoroughly understood in all its bearings. He was a generous landlord and a popular county man, and his loss to the parish of Warnham, where he restored the church, is one which must be severely felt for many years; while his genial presence and his ever ready sympathy with all who came for advice will long be remembered in the business world of London, by the members of his staff, and in many humble homes in Sussex.

JOHN HENDERSON PORTER was born on the 10th of June, 1824. His career dates from the early days of railway enterprise, which gave rise to a great demand for iron roofing and ironwork construction generally, in which he was engaged as assistant to his

father then established at Southwark. He interested himself greatly in the important industry of galvanizing iron and in 1842 brought back from Paris, where he had studied the process and its adaptations, skilled workmen with whose aid he commenced operations in this country. It may be interesting to record that he launched the enterprise by dipping the first sheet of iron with his own hands. Walker's patent for corrugating iron expiring at this time, Mr. Porter at once led the way in applying galvanized iron corrugated for roofing and other purposes. In 1848 he took out a patent[1] for iron girders, and another[2] for applying corrugated iron for floors and roofs, in which he made use of corrugated iron arches, laid with concrete; also of horizontal plates corrugated to a special form. Both these kinds of flooring were constructed by him for cotton mills and for iron bridges supplied to foreign governments. In these matters he was, however, in advance of his time and anticipated by more than twenty years inventions upon the same lines now meeting with adoption.

Succeeding to his father's business, Mr. Porter removed to Birmingham, where his firm was engaged for several years in the construction of iron roofs, bridges, piers, dock gates and light-houses, including several cast-iron lighthouses for the Russian Government and others of wrought-iron framing for the Spanish Government. One of the latter, the Buda Lighthouse, 150 feet high to Mr. Porter's design, formed the subject of a Paper read in 1861 at a meeting of the Institution of Mechanical Engineers at Birmingham, where the lighthouse was temporarily erected.[3] Besides many other bridges erected abroad, the Lambeth Suspension Bridge over the Thames was constructed by Mr. Porter's firm to the design of Mr. Peter Barlow, in 1862.[4]

From 1867 to 1875 Mr. Porter was engaged with Mr. James Duncan in the manufacture of beet root sugar at Mr. Duncan's factory at Lavenham in Suffolk, where the sugar beet was extensively cultivated by the farmers to supply the factory, under special arrangement. He wrote a pamphlet on this subject in 1870 and also dealt with it in a Paper read at the Ixworth Farmer's Club in 1874.[5] The utilization of the residual pulp for stock feeding was an important branch of this system; and a practical demonstration of its value for that purpose was made in

[1] Specification No. 12,091, 8 March, 1848.
[2] Specification No. 12,356, 2 December, 1848.
[3] Proceedings Institution of Mechanical Engineers, 1861, p. 15.
[4] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 284.
[5] The pamphlet and Paper are in the Library of the Institution.

an extensive range of cattle-feeding sheds erected at the factory, which was highly successful in its results.

The industry, however, failed to establish itself in this country, notwithstanding Mr. Duncan's spirited enterprise, and Mr. Porter, who was now practising as a Consulting Engineer in London, next had his attention directed to the softening and purifying of water, for which purpose he made use of the Clark process. This had previously only been available, and in but few instances, for the treatment of water on a very large scale; but Mr. Porter succeeded in utilizing it in suitable plant of his own design for the purpose of "softening and filtering water in large quantities within small space," as expressed in the specification of the patent which he obtained in 1876.[1] This was followed by other patents[2] for further improvements in the process, now well known as the Porter-Clark process, to the development of which his attention was continually devoted till the time of his death.[3]

Mr. Porter was possessed of a natural faculty and taste for construction, with great power of initiation and organization. With these qualities were combined force of character and a considerate bearing which commanded the respect and regard of equals and subordinates alike. In private life he was genial and humorous, modest and retiring, and he was much respected by all who knew him intimately. He was a great reader and had a fine taste for art and a happy power of expression in conversation and in writing. After an illness of three months from "Lymphangeites" he expired on the 14th of October, 1895. Mr. Porter was elected an Associate, on the proposal of Mr. I. K. Brunel, on the 3rd of December, 1850, and on more than one occasion took part in discussions at the Institution.

GEORGE HARLOWE SUMNER, second son of the late Dr. William Allen Sumner, was born at St. John's Wood, London, on the 7th March, 1853. When not yet fifteen he went to Brazil as an apprentice under Mr. A. F. Wilson in the service of the Pará Gas Company. He went through the various grades in that Company, until he became Manager in 1879, which position he held for five years. He then started in Pará on his own account

[1] Specification No. 1697, 21 April, 1876.

[2] Specification Nos. 1990, 20 May, 1879, and 3040, 11 July, 1881.

[3] Several pamphlets on this subject by Mr. Porter are in the Library of the Institution.

as a mechanical and consulting engineer, and succeeded in obtaining several contracts from the Brazilian Government. Mr. Sumner died at sea on the 14th November, 1895, from beri-beri, a disease prevalent in Brazil, somewhat of a paralytic character, accompanied by swelling of the limbs. He had undertaken a voyage from Pará to Ceará in the hope that change and sea-air would effect a cure. Mr. Sumner was a Freemason and held the post of Provincial Grand Master at Pará. He was elected an Associate on the 4th February, 1879.

*** The following deaths have also been made known since the 26th February, 1896:—

Members.

Barry, Philip; *born* 1832; *died* 11 November, 1895.

Bond, George; *born* 9 December, 1840; *died* 22 April, 1896. (*Heart disease.*)

Church, Jabez; *born* 1845; *died* 20 March, 1896. (*Congestion of the lungs and heart disease.*)

Davis, John Henry; *born* 24 December, 1837; *died* 20 February, 1896.

Fishenden, Frederic George; *born* 31 July, 1832; *died* 10 April, 1896.

Levinge, Harry Corbyn, B.A.; *born* 1 December, 1828; *died* 11 March, 1896. (*Heart disease.*)

Logan, David; *died* 17 April, 1896. *aged* 65.

Longridge, James Atkinson; *born* 31 May, 1817; *died* 15 April, 1896.

Margary, Peter John; *born* 2 June, 1820; *died* 29 April, 1896. (*Heart disease.*)

Meik, Thomas; *born* 20 January, 1812; *died* 22 April, 1896.

Stanley, Douglas Austhwaite; *born* 24 Sept., 1838; *died* 2 March, 1896.

Associate Members.

Adley, Charles Coles; *born* 10 September, 1828; *died* 11 April, 1896. (*Inflammation of the lungs.*)

Benest, James Smyth; *born* 26 March, 1826; *died* 29 February, 1896. (*Congestion of the lungs.*)

Day, Edward Hugh; *born* 30 July, 1868; *died* 31 March, 1896. (*Cholera.*)

Fenwick, John; *died* 20 April, 1896.

Hunt, Herbert Edgell; *born* 25 November, 1847; *died* 7 March, 1896.

Melisurgo-Melissenos, Giulio Cesare Alessandro; *born* 1837; *died* 6 May, 1896. (*Pneumonia.*)

Phillips, Henry Parnham; *born* 26 October, 1856; *died* 30 March, 1896.

Protheroe, David Thomas Rhys. *born* 30 June, 1856; *died* 2 April, 1896.

Sadasewjee, Jagannath; *born* 2 November, 1826; *died* 26 March, 1896. (*Paralysis.*)

Taylor, Norman Maughan; *born* 17 July, 1868; *died* 22 May, 1896.

Associate.

Clutton, John; *born* 29 August, 1809; *died* 1 March, 1896. (*Pneumonia.*)

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—Sec. Inst. C.E., 2 *June*, 1896.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The International Congress for the Unification of the Methods of Testing Materials for Building and Construction.

(Zeitschrift des Vereines deutscher Ingenieure, Sept. 28th, 1895, p. 1,168.)

The fifth meeting of this Congress was held at Zurich in September, 1895; it was more truly international in character than any of its predecessors, and was attended by 320 members, of whom, however, only two were English and four American. Prof. Tetmajer, who presided, opened the Congress with an address describing the objects of these meetings. These are expressed in the title of the Congress, but the resolutions passed are merely the opinion of the majority on various technical questions of interest, and are in no sense binding on the members attending the Congress, while by means of the committee reports and the resolutions passed, information is gained as to the various methods of testing materials, and the direction in which work remains to be done. He also referred to the work of the French Commission on testing,[1] the reports of which were placed before the meeting. In view also of the loose organisation of these Congresses, and their lack of financial resources, a set of regulations had been drawn up, and would be laid before the Congress for adoption later on.

Prof. Kick of Vienna then spoke referring to the late Prof. Bauschinger, the originator in 1884 of these Congresses; and the remainder of the first day was spent in sectional meetings, and in an excursion to the Uetliberg Railway.

The second day was begun with two Papers dealing with the methods of chemical analysis of iron and steel. The first, by Dr. Wedding of Berlin, dealt more generally with the subject, pointing out the existing difficulties and the various sources of error in sampling and testing; such as differences due to variations in the material tested, impurities in the reagents, personal errors due to the chemist, and differences due to different methods. In the second Paper, by Dr. von Jüptner of the Neuberg Steel Works, to these were added errors due to the instruments employed, and the want

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 465.

of better recognised and ascertained atomic weights. Dr. von Jüptner gave an instance of a steel ingot in which the percentage of carbon in samples taken from the top and the bottom varied from 0·92 per cent. to 0·37 per cent., and the phosphorus from 0·261 per cent. to 0·096 per cent. Both speakers drew a strong distinction between the exact analyses for scientific purposes where time is no object, while absolute accuracy is aimed at, and the rougher methods for manufacturing purposes where time is of importance, and quicker and cheaper methods are employed. After a brief discussion, the general committee was instructed to form an international committee to investigate the question of uniformity in the methods of analysing and sampling iron and steel.[1]

Prof. Steiner of Prague next read a Paper on the behaviour of iron and steel at very low temperatures. He showed from his own experiments, as well as from the researches of others, that low temperatures affect wrought iron and steel in a marked degree, the tensile strength and limit of elasticity being increased, while the brittleness is increased and the ductility is diminished. While, however, other authorities do not think these variations are of sufficient importance to be taken into consideration, owing to the comparatively small differences of temperature occurring in practice, Prof. Steiner states that he has experienced objectionable changes within the ordinary limits of variation of temperature. The majority of the Congress, however, did not share Prof. Steiner's views, though the question was referred to a sub-committee for further investigation.

An interesting report was laid before the Congress by the committee appointed in 1890 to inquire into the causes of abnormal behaviour of mild steel (manufactured either by the open hearth or the Bessemer process) as evidenced by sudden and seemingly inexplicable fractures. The chairman, Mr. Eckermann of Hamburg, had issued a circular, the replies to which were laid before the Congress. This circular asked for answers to three questions: (i) What recent instances of treacherous behaviour of ingot-iron had been experienced; (ii) Whether improvements in manufacture had rendered the occurrence of such fractures rare; (iii) What means exist of detecting with certainty this abnormal condition of ingot-iron. A large number of replies had been received, and the report formed a pamphlet of fifty-eight pages. These replies were unanimous in their opinion that such fractures are now very rare, and it was pointed out that in every case, proper inquiry had resulted in proving such behaviour to be traceable either to mistakes in manufacture, or to unfair treatment of the material after rolling; such as working at the critical temperature, undue strains during working, and so on. Many

[1] Reports of these two Papers are given at some length in the "Oesterreichische Zeitschrift für Berg- und Hüttenwesen," for October 12, 26, and November 23, 1895.

instances were quoted of treacherous fracture and the causes to which they were traceable. The committee reported that, "We now know the substances which, if contained in ingot-iron, render it brittle; we know the limits up to which such admixtures are harmless, and we are always able by analysis to determine the existence and quantity of such admixtures. We also know the precise limits to which demands on the tensile strength and ductility can be made with safety, and we know exactly the faults which must be avoided in the working of the material after it leaves the rolls. Nothing further therefore remains to be done in order to elucidate this alleged abnormal behaviour of ingot-iron, and there is no reason for the committee to continue its work." This report, however, was not adopted in its entirety by the meeting, which decided that the committee should continue to exist "to make further investigations as to the applicability of ingot-iron."

On the third day Mr. Henning of New York read a Paper on his experiments made in conjunction with Mr. Keep on cast-iron, which has been already published. Prof. Ledebur of Freiberg reported on the property of iron to turn brittle when immersed in weak acids, ascribing this to the action of the nascent hydrogen on the surface of the iron. This brittleness passes off if the iron is stored for a long period in a dry place, or if it is heated; and the meeting decided that this question is now finally settled.

Prof. Martens reported on the microscopic examination of metals, but owing to differences of opinion on several details, the meeting decided that this committee should continue its work.

Papers on several other subjects were discussed, but the reports of them are not yet published. A motion by Mr. Schrödter of Düsseldorf "That endeavours be made to introduce international standards for quality, testing and approving of iron and steel materials of all descriptions" was referred to the permanent committee.

Finally, the Code of Regulations referred to by Prof. Tetmajer in his opening speech was adopted, constituting an "International Union for the testing of technical materials." By these rules members can be elected on proposal by two existing members, the yearly subscription being 4*s*., members being entitled to copies of the official periodical at a reduced rate. The first standing committee was elected under these new rules, Prof. Tetmajer being unanimously chosen president. The next meeting will take place at Stockholm in 1897.

R. B. M.

NOTE.—Prof. Geo. Lunge, Ph.D., of the Federal Polytechnical School at Zürich, has presented to the Institution a report of the proceedings of the Congress, and this can be seen in the Library.

On the use of Punching and Shearing as a means of Testing Metals. By L. Baclé and C. Frémont.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 713.)

In two previous notes [1] it was shown that the work done in punching and shearing metal could be recorded by an apparatus, a drawing of which accompanies the present communication. Further investigations have led to the conclusion that by this method the testing of a given sample of metal may be effected in the course of its manipulation in the workshop, without the preparation of special test-pieces. The curves are obtained by recording simultaneously as ordinate and abscissa the downward movement of the punch, and the yielding of the swan's neck of the machine. Experiments were made upon metals of various degrees of hardness, from copper to steel, and it was found that each sample gave a characteristic and constant form of diagram, even when a different tool was used. The Authors point out that the area of each curve necessarily includes the work done in expelling the piece from the hole, and cannot therefore be interpreted in quite the same way as the diagram of an ordinary testing-machine. They have found that with bars of the same metal, from 5 millimetres to 25 millimetres thick, the maximum ordinate is directly proportional to the thickness, and also that the breaking load in the operation of punching is always approximately seven-tenths of the load which would just break a rod of metal of the same diameter as the piece cut out. In each diagram the hardness of the metal is indicated by the steepness of the curve near its origin. Beyond this, a sudden change of slope affords evidence of the malleability of the sample, and this again is followed by a still gentler rise to the point of maximum effort, corresponding to the total rupture of the metal. The horizontal length of this part of the diagram is greater according as the material is more ductile. From a large number of experiments the Authors conclude that this method, from its easy applicability, may prove more useful than the ordinary process of testing.

G. J. B.

Report on Arched Structures.[2]

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, 1895, Special Appendix.)

With the view of corroborating or establishing by actual experiment the data and methods of theoretical calculations adopted in

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[1] Comptes Rendus, December 10, 1894, and June 24, 1895.

[2] This report, "Bericht des Gewölbe-Auschusses," has been published in a separate form by the Austrian Engineers' Society.

the design of arched structures, the Austrian Engineers' and Architects' Association nominated a representative committee to supervise the carrying out of such experiments as were advisable for the purpose of comparison; the systems of construction tested being arches in masonry, brickwork, concrete, Monier framing with concrete, and steel.

The work of investigation and calculation was entrusted to various sub-committees of experts; and their several reports are issued conjointly by the Association.

The following is a brief epitome of the proceedings:

I. Trials to breaking-point of arches, vaulting, and composite spans used in superstructure. Tests carried out on seventeen structures of following spans and materials: (*a*) 4-foot 5-inch span: two brick, four composite, 1 concrete; (*b*) 8-foot 10-inch span: one brick, one composite, one concrete, two Monier system and two of corrugated iron; (*c*) 13-foot 3-inch span: one brick, one concrete, one Monier system. To this series was also added one on Melan system.

The test structures were erected in series, each being 6 feet 6 inches in width, the piers being rigidly fixed by iron ties, and the sides constructed between iron framings, so that each was entirely self-contained, no thrust being by any possibility communicated to the adjacent structures, and so also that the breaking down of any one structure should not dislocate or injure the others. The loading was effected by pig-iron, placed on the arch from an independent gangway. The whole of the structures were carefully erected with the best materials, and allowed to set for four months before being experimented upon. The 4-foot 5-inch spans were fully loaded; in the two larger sizes the loads were concentrated on the half-span. The normal live-load was taken at 124 lbs. per square foot, and factor of safety = 8; so that the theoretical limit of strength was 992 lbs. per square foot.

In series (*a*) none of the structures showed any sign of weakness when loaded up to this limit. In the brick arches, in lime mortar, which were 6 inches in thickness, and with a rise of $5\frac{3}{4}$ inches, the load was continued up to 1,435 lbs. per square foot, at which point some slight cracks were visible, but there was no appreciable settlement or failure to carry the load. The four composite structures consisted of interlocking tiles or lintols, constructed on different systems, and finished over with a thin layer of concrete. The first two failed under loads of 1,640 and 1,653 lbs. per square foot respectively; the remaining two (systems Schober and Hönel) carrying in safety loads of 1,648 and 1,718 lbs. per square foot, and showing when examined no sign of damage. These results were unexpectedly high, and pointed to the advisability of avoiding complicated forms of interlocking tiles, and to the necessity of perfectly rigid metal framing. The concrete arch was 6 inches thick, rise 5 inches and of a mixture of one of Portland cement and five of sand, well rammed; in this the loading was practically

equivalent to the brick arch, and the results similar. The margin of safety was evidently sufficiently high for the system of construction to be suitable for all practical requirements.

In series (*b*), in which the loads were concentrated on the half-span, the whole of the arches were tested to breaking point. The brick arch (6 inches thick and 10 inches rise) failed under a load of 884 lbs. per square foot, the deflection before fracture being 2·08 inches. In the concrete arch, $3\frac{3}{8}$ inches thick and 9 inches rise, composed of mixture of one cement to four sand, signs of weakness were noted at 615 lbs. per square foot, and rupture occurred under a load of 1,128 lbs. per square foot. The arches constructed of iron network bedded in concrete (Monier system) broke down at loads of 1,218 and 1,321 lbs. respectively. The composite span (Hönel's system), which was 4 inches in thickness with a rise of $5\frac{1}{2}$ inches, failed under a load of 496 lbs. per square foot; the corrugated iron arch, rise 10 inches, composed of ordinary sheets 0·039 inch thick, corrugations $3\frac{1}{2}$ inches by 2 inches, gave way at 974 lbs. per square foot; and when strengthened at the edges with angle iron, $2\frac{3}{8}$ inches by $2\frac{3}{8}$ inches by $\frac{1}{4}$ inch, sustained 1,100 lbs. per square foot before fracture.

In series (*c*)—13 feet 3 inches span—the brick arch, $5\frac{1}{2}$ inches in thickness and $13\frac{1}{2}$ inches rise, showed flaw at 137 lbs. per square foot, and broke down under load of 275 lbs. per square foot. The concrete arch, 4 inches thick and 1 foot $3\frac{3}{4}$ inches rise, showed the first crack at about 420 lbs. per square foot, and was fractured at 792 lbs. per square foot. The Monier combination arch, 2 inches thick at the crown and 1 foot $3\frac{3}{4}$ inches rise, showed the first sign of weakness also at about 420 lbs. per square foot, and was finally crushed at 894 lbs. per square foot.

After the preliminary experiments had been arranged for, a fourth type of structure was added; this being a specimen of vaulting on Melan's system, which consists of small steel joists bent to the curve of the arch, about 3 feet apart, the intervening part being filled with concrete. The rise given was $11\frac{1}{2}$ inches, and thickness (equal depth of joists) $3\frac{3}{16}$ inches. At the first testing, the trial was stopped for want of further loading material, at 1,414 lbs. per square foot; at which point the deflection was very slight, and the structure had sustained no appreciable damage. On resumption of the trial, the load was concentrated at one point, up to 152 tons, at which signs of failure were visible; the arch finally subsiding in hopper form under a concentrated load of 164 tons. This was considered as an excellent result.

II. Trials of arches of larger span, *e.g.*, bridges.

These experiments were carried out in two series, viz., A, two arches 32 feet 10 inches span, constructed respectively of concrete and on Monier system, and erected in the railway station yard at Matzleinsdorf; and B, five arches (stone, brick, concrete, Monier and steel) all of 75 feet 6 inches span, erected at the Purkersdorf quarries.

A. Arches 32 feet 10 inches span, 3 feet 3½ inches rise, 13 feet 2 inches in width. Monier framed arch, framing formed of longitudinal rods 0·39 inch diameter and transverse rods 0·276 inch diameter, forming meshes 2·17 inches square. This network was formed near the soffit of the arch, the concrete being filled in to thickness of 6 inches at crown and 8 inches at springing. The structure was allowed to stand for 210 days after completion before being tested. A connection was made from a siding, and the first tests were made by running two engines across; one three-axle, weighing 33½ tons, and the other four-axle, weighing 48½ tons. In both cases the load was concentrated on one-half, and there was no sign of weakness in the arch. Further tests were then applied by loading over the structure with rails. At 90 tons load (= 922 lbs. per square foot) one spandril showed signs of damage; the arch was then unloaded, and reloaded up to 180 tons, at which point the abutments began to crush in, allowing the arch to drop (the centering being kept 6 inches clear of the soffit) but without showing any cracks. At 192·6 tons (2,011 lbs. per square foot) the abutments were thrust out nearly 16 inches, and the failure of these allowed the arch to break down at 196·2 tons; showing a crack at one springing, and a crack partly through at about one-third of the half-span from the opposite springing.

The concrete arch, of same dimensions, was formed of 1 part Portland cement, 3 parts clean Danube sand, and 1 part broken limestone. It was allowed to stand for 224 days before testing. On the first day of trial the load was continued up to 1,041 lbs. per square foot; cracks in one abutment were visible at 520 lbs. per square foot, but no damage was done to the arch. On the second day the loading was continued up to 206·4 tons (2,116 lbs. per square foot), which was all the loading material available; this was kept on for three days, small cracks being visible in the soffit, and larger cracks in the spandrils. The maximum deflection at crown was 1·12 inch; and when the load was removed the permanent set was 0·63 inch. These tests showed the necessity not only of careful construction of the arch itself, but also of the greatest care in relation to the abutments and spandrils.

B. Arches 75 feet 6 inches span, 15 feet 1⅛ inch rise, and 6 feet 6 inches wide. These structures were calculated for a uniform safe distributed load of 34½ tons on the half-span = 0·91 ton per lineal foot, or 308 lbs. per square foot. The load was obtained by piling up rails from one abutment to the crown, these being carried on transverse rails spaced at equal distances apart; the load being therefore concentrated at these points.

The masonry and brick arches were constructed to the same dimensions, viz., span and rise as above (radius of arch = 54 feet 8½ inches), thickness at crown = 1 foot 11⅝ inches, thickness at springing = 3 feet 7½ inches; both built in Portland cement mortar of 1 cement to 2·6 sand. The breaking loads were: stone

arch, 2 tons per lineal foot, or 709 lbs. per square foot; brick arch, 1·8 ton per lineal foot, or 638 lbs. per square foot.

The concrete arch, of the same span, rise, and width, had a thickness throughout of 2 feet 3½ inches. The mixture employed varied in different parts, according to the theoretical distribution of the strains, being respectively 1 : 2, 1 : 5, and 1 : 8. The structure stood for three months before testing, and the breaking load was 2·2 tons per lineal foot, or 780 lbs. per square foot. The various mixtures were clearly defined. It is, however, open to doubt if it would not have been better to form the whole structure of one and the same mixture.

In the Monier arch, the network was formed of longitudinal rods 0·55 inch diameter, and transverse rods 0·276 inch diameter, with mesh 2½ inches square. The thickness of concrete at the crown was 1 foot 1¾ inch and at haunches 1 foot 11⅝ inches. The breaking-load was 3·87 tons per lineal foot, or 1,344 lbs. per square foot. The concrete was of remarkable tenacity, and the work of breaking up the structure was one of extreme difficulty.

The metal arch was constructed of soft steel. The arched girder had the same span and rise as the other arches, and was constructed with web 0·39 inch thick, 12½ inches deep, with angle-steels 3½ inches by 3½ inches by $\frac{7}{16}$ inch, and flanges 8 inches by 0·31 inch. With a load of 0·45 ton per lineal foot the strain was not to exceed 7 tons per square inch. The loading was continued to 157 tons, at which point the deflection was so great that the safety staging had to be altered; but the settlement was perfectly regular throughout the structure, no flaws being visible nor any rivets sprung. There was a certain amount of lateral deformation. The loading was stopped at 175 tons, at which point the equivalent distributed load was 4·65 tons per lineal foot, or 1,580 lbs. per square foot.

III. This section of the Committee's work was allotted to the specific measurement and examination of the alteration of form undergone by the several structures. The arrangements and apparatus are fully described, with numerous plates and reproductions of photographs of fractures; tabular summaries of the strains throughout are also appended.

IV. To this section was allotted the testing of all the cement and other materials employed; and the determination of the tenacity and compressive strength and modulus of elasticity of the several materials. The graphic determination of strains and the proofs of the calculations of the results of all the tests were dealt with under section V.

VI. Under this section are grouped in comparative tabulation the results of the trials of the larger structures (75 feet 6 inches span). The alterations of form in the axis of the arch occurred in each case practically in proportion to the load. The first fissures started very quietly, and grew slowly and almost imperceptibly. After the first fissure became evident, the limit of

strength of the structure was by no means reached; this is clearly shown in the subjoined Table:—

Type of Arch.	Load in Tons to Point of First Alteration in Form.	Load in Tons to Appearance of First Fissure.	Load in Tons to Breaking Point.	Percentage Increase from First Fissure to Breaking Point.
Stone	35·075	56·51	74·022	30
Brick	35·075	42·20	67·548	59
Concrete	56·907	63·25	83·275	31
Monier	56·693	78·53	146·120	86

VII. This section is devoted to general remarks on matters of construction to which attention is specially directed.

In bridges for railways and heavy loads, where the rise is not less than one-fifth of the span, the thickness of arch at crown is scheduled as:—

$l =$	ft.	ins.	$d =$	ft.	ins.
	98	0		3	$7\frac{1}{2}$
	131	0		4	7
	213	0		7	$2\frac{1}{2}$
	262	6		8	$10\frac{1}{2}$
	328	0		11	2
	393	0		13	$5\frac{1}{2}$

and d' (thickness at springing) = in segmental arches 1·5 d, and in semi-circular arches 1·7 d.

The minimum width of the arch at the crown is also scheduled as for—

$l =$	ft.	ins.	$w =$	ft.	ins.
	98	0		7	$10\frac{1}{2}$
	131	0		9	10
	213	0		14	9
	262	6		18	$4\frac{1}{2}$
	328	0		23	0
	393	0		28	$2\frac{1}{2}$

If less than this, it is advisable to construct the faces to a batter of at least 1 : 20.

For arches exceeding 131 feet span, the cubic contents of any one block of material should not be less than 25 cubic feet.

There are three Appendixes to the report, containing respectively the static calculations for (A) steel arched girder, (B) Monier arch, and (C) concrete arch.

P. W. B.

The Maintenance of Asphalt Flooring. By — Boedecker.

(Verein für Eisenbahnkunde, 1894, p. 218.)

From the observations which the Author has made during the last six years on the maintenance of asphalt flooring on the Berlin and Potsdam Railway, he has found that the asphalt which is obtained in Berlin cannot be relied upon. In his opinion this result is due to the foreign ingredients introduced into the asphalt, and if pure bitumen and gravel were used the result would be entirely different. The asphalt flooring under the roof of Potsdam station, which was laid when the station was built, was partly renewed in the course of the past year; it was found that the upper layer was cracked, dry, and crumbling, but the lower portion was in a good state of preservation. All dirt and dust were removed from this lower portion, and a coat of "Adiodon" was then laid upon it, and the whole was covered with sand. "Adiodon" is a kind of varnish introduced by St. Valentino Asphalt company, and is made out of Abruzzi asphalt; it remains pliable after becoming dry, penetrates into the cracks underneath, and firmly unites with the asphalt. The parts of the flooring treated in this way have proved very satisfactory. The cost of this coat is $1\frac{3}{4}d.$ per square yard, which amounts to about half of the ordinary maintenance cost of flooring; it will adhere equally well to moist surfaces, and is therefore often used for the damp courses of buildings with good results.

With regard to asphalt flooring in the open air, the Author has not during the last few years repaired it with asphalt, but has laid on it a coat of Meissner's roof varnish, upon which a thin layer of gravel—of the size of peas—is laid. Such a coating costs, inclusive of all labour, about 7*d.* a square yard. It gives a good appearance to the asphalt, and is kept in repair very cheaply. In the case of coverings required to be watertight, this method of repairing asphalt does not answer, but the Author has used it directly on the surface to be protected, with a thin layer of gravel, and it has given excellent results. It attaches itself satisfactorily to stone, iron, or wood-work. A portion of the platforms outside the roof of Potsdam station was repaired with the roof varnish two years ago, and shows a uniform grain, and promises to be very durable.

J. A. T.

Railway Bridge over the Danube at Cernavoda.

By Professor Melan.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1895, p. 517.)

This structure has recently, after five years' work, been completed by the Roumanian Government. It forms part of the line crossing the Danube valley between Fetesti and Cernavoda, on

the main line from Bucharest to Constanza on the Black Sea. Leaving Fetesti, the line first crosses the Borcea arm of the Danube by a bridge 3,255 feet in length, comprising three spans of 459 feet 4 inches each and eleven side-spans or flood-openings of 164 feet each. The rail-level is 40 feet above high water, and after clearing the river falls at an inclination of 1 in 100 towards the marshy island, about 8 miles in width, across which it runs on the horizontal at a height of 10 feet above high water, crossing—near the centre of the island—the Balta Viaduct, 4,774 feet in length. This consists of thirty-four spans of 140 feet 5 inches each, on the Schwedler type. The line then rises again at 1 in 100 to the viaduct over the main stream, over which the rail-level is 103 feet above high water. The approach viaduct consists of fifteen spans of 200 feet each, centre to centre of piers. The total length of the structure is 5,456 feet. The bridge proper consists of five spans; the central one being of 623 feet 4 inches, and those at each side 459 feet 4 inches. The system of construction is two double cantilever structures, the central or equilibrium bays being the second and fourth spans, with 164 feet cantilevers over the first and third, and third and fifth spans respectively. The free ends of the cantilevers and the two abutments carry three half-parabolic girders of 295 feet 4 inches span, 29 feet 6 inches deep at each end and 42 feet 8 inches deep at centre. The piers are 105 feet high above rail-level, or 208 feet above high water; the depth of truss at centre of each span being 55 feet 9 inches. These main trusses are inclined vertically at 1 : 10, and are double-lattice braced. The bridge floor is a trough platform, in which the transverse sleepers are bedded in asphalt concrete.

The material of which the bridge is constructed is medium soft steel, specified as under, viz.:—

Ultimate tensile strength: minimum . .	26·7 tons per square inch.
„ „ „ maximum . .	30·5 „ „ „
„ extension	20 per cent.
Limit of elasticity	15·25 tons per square inch.

The working strain (allowing 20 per cent. for wind-pressure in addition to the dead and live loads) is taken at $7\frac{1}{2}$ tons per square inch.

The work of constructing the foundations was proceeded with in the usual manner, although in the Cernavoda bridge the great depth (over 100 feet below low-water level) made the compressed-air working very difficult; and in spite of all precautions, several fatalities occurred. The main trusses were erected on staging near the water-level, and were raised by hydraulic-presses on iron columns built in with the piers, and lengthened as the height of the pier increased. To each truss there were four columns, two at each end; one being for carrying the load, while the other was lengthened before transferring the load. By this means the fresh masonry work was never overloaded. The load on each column was about 380 tons.

The total length of metal structures on the 9¼ miles of line from Fetesti to Cernavoda is 13,455 feet. The Borcea bridge contains about 2,600 tons of steel and ironwork, and cost £134,475; the Cernavoda bridge contains about 5,000 tons, and cost £311,320. The total cost of the 9¼ miles of railway was about £1,200,000.[1]

P. W. B.

Ship-Canal Lock at Sault Sainte-Marie, Michigan.

(Engineering News and American Railway Journal, vol. xxxiv., 1895, p. 194 *et seq.*)

This work has been constructed by the United States Government, having been undertaken, in connection with the deepening and improvement of the Detroit and St. Mary's rivers, to give the United States an independent waterway 20 feet deep from Buffalo to Duluth. The channel through Hay Lake is 300 feet in width; and at the north-west end the rapids in the St. Mary's river formerly barred all navigation. They extended for a length of 3,500 feet, having a width of about 2,300 feet, an average depth of water of about 2 feet 6 inches on a boulder-strewn rock bottom, and a total fall of about 18 feet from the level of Lake Superior to that of Lakes Huron and Michigan. The Canadian canal and lock are on the northern bank; and the old 16-feet deep United States canal on the southern bank, with its 500 feet lock, is now superseded by the new channel and the lock, 800 feet long and 100 feet wide, which has been under construction since 1887. The site chosen adjoins the old lock. The quantity of material excavated has been 130,085 cubic yards earth and 106,602 cubic yards rock. The only difficulty encountered in this portion of the work was occasioned by portion of the cofferdam being washed away by a spring from a crevice in the bed-rock. Attempts were made to stop the water by piling and puddling, but to no avail. Recourse was therefore had to a device resembling a pile-driver, by which small cylinders of clay were forced down a 3-inch pipe inserted into the crevice, until the fissure was entirely plugged.

The concrete was composed of 1 part of cement, 1½ part of clean sharp quartzose sand pumped from the bottom of the river, and 4 parts of broken red sandstone from the excavation itself, crushed to pass through a 2-inch ring and screened. The masonry (80,876 cubic yards) was a close-grained limestone. This work was laid from two 16-feet gauge longitudinal tracks, parallel with the lock-walls, and fitted with travelling cranes, the material being conveyed on to the site by intermediate sidings.

The rock-bed, having been cleaned and levelled, was floated over with a thin coating of mortar, on which the concrete bed was formed. Upon this were constructed the six inlet and six outlet

[1] A longer and more fully illustrated account of this bridge will be found in the Allgemeine Bauzeiting, vol. lxi. p. 25. Vienna, 1896.

culverts, each 8 feet square. Of the former, four run the whole length of the lock, and two half the length, and all have openings 3 feet square at suitable intervals. The culverts are formed entirely of timber.

The lock-gates are five in number, viz., the upper, upper guard, intermediate, lower, and lower guard gates. Each gate consists of two leaves, the mean line forming the arc of a circle of 77 feet 3·38 inches radius, the chord of median line = 103 feet 5·08 inches. The upper and upper guard gates are 26 feet 6 inches high, the intermediate and lower gates 43 feet high, and the lower guard gates 25 feet 6 inches high. The gates are constructed of soft steel, and the anchor bolts and connections of forged high-carbon steel, of the following respective qualities :—

—	Soft Steel.	Hard Steel.
	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.
Ultimate tensile strength (minimum and maximum)	58,000–63,000	69,000–74,000
Elastic limit	32,000	38,000
Percentage elongation in 8 inches	26	18
Do. reduction at fracture	50	38

The total weight of metal in the five gates is about 1,287 tons.

The inlet and outlet culverts are closed by twelve "butterfly" valves : steel shutters on central horizontal pivoted axis, set in cast-iron frames.

The pumping machinery for emptying the lock is contained in one large power-house. The main discharge is effected by three 30-inch centrifugal pumps, each driven by a Westinghouse compound engine, steam supplied by two 375 HP. Babcock and Wilcox boilers. For drawing off water from the lowest levels, also for any bottom leakage, there is in addition a 10-inch centrifugal pump driven by belting from a turbine.

Hydraulic engines are employed for working both the lock-gates and the large butterfly-valves for closing the inlet and outlet culverts. The water from the upper level is conveyed by a supply-pipe 6 feet in diameter to two horizontal turbines in a wheel-pit in the power-house. These turbines operate three pumps which feed three corresponding accumulators, 18 inches diameter by 98 inches plunger-stroke ; and from these the water is supplied to the hydraulic engines working the gates and valves. The valves are worked by horizontal direct-acting engines, 8 inches diameter cylinder and 48 inches stroke. For the gates there are six machines, one for each leaf of the upper and lower lock-gates and the intermediate gates. Each machine comprises two three-cylinder engines. The cables are hemp core with steel sheathing, 1 inch diameter, and tested to a tensile strength of 100,000 lbs.

P. W. B.

The Ports of Trieste and Fiume in 1895.

By Friedrich Bömches.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1895, p. 396.)

The present communication is the substance of notes made by the Author when recently revisiting Trieste and Fiume; the particular points to which his attention was directed being the conditions of stability of the various harbour works, which have been described in previous Papers.

In the harbour of Trieste four basins had been completed in 1893; the smallest of these, at the northern end of the port, being enclosed by the outer pier, and the three others by the breakwater. This affords ample protection from seaward, but the harbour is subject to violent disturbance from the "bora"—the north-east, or land wind—to escape whose irresistible force, vessels frequently remain in the open sea. Experience has shown that the dimensions of the jetties are too narrow, great difficulty being experienced in manœuvring large steamers. The general depth of water (28 feet) is ample and is well maintained. The Cyclopean block base on which the jetties and breakwater are constructed has not yet, after (in some cases) nearly twenty-five years, attained a condition of repose, the various structures being still subject not only to vertical but also to lateral settlement. The breakwater is standing best, having settled fairly uniformly to the extent of about 3 feet without any dislocation of the parapet or of the inner face. The structure was some years back raised 2 feet 3 inches. The chief alterations have occurred in the quays and jetties, which have suffered not only settlement but dislocation. The last finished portion of the work (completed in 1893) already shows signs of disturbance, and will evidently require a considerable degree of reconstruction. The outer jetty of the first basin has suffered worst of all, especially on the inner side, where great fissures and dislocations are visible. The probable cause is the overloading of this area. The soil over the whole site of the port is, in fact, very soft and yielding, and should not be loaded to any extreme degree.

At Fiume the harbour-system comprises three large basins, with a pier extending from a headland to the south-east and forming a well-protected outer port. There is also a special basin for the petroleum trade and another for the timber trade of the port. The harbour works have been well developed in proportion to the growth of trade, and are capable of further systematic extension. The mean depth of water is 26 feet 6 inches. The chief drawback to the quays is the limited width available. The construction of the quays and jetties is similar to that of Trieste, but the work here has stood much better, the ground being firmer and the sea less violent. The breakwater, however, which is in parts in 130 feet depth of water, has sunk in several places. At one point

a length of about 1,000 feet suddenly vanished in a calm sea, having by its immense weight forced in a soft area at the bottom, which buried the whole mass. The land accommodation and approaches at Fiume are inferior to those at Trieste, but the harbour itself at the former place is ampler and more protected.

P. W. B.

The Reconstruction of a Portion of the Oswego Outer Breakwater.[1]

Report by W. Pierson Judson, U.S. Engineers, M. Inst. C.E.

The outer breakwater at Oswego, N.Y., on Lake Ontario, is formed of wooden cribs or framework filled with loose stone, sunk in position and firmly fastened together, and was constructed in 1876. In 1889 a small spur of similar construction, 150 feet long, was added, projecting outwards near the middle of the breakwater. This caused a concentration of the wave-action at this point, followed by a breach in the breakwater in December, 1889, and again in February, 1890. These were made good, while a more serious breach at the same place in the winter of 1891–92 was repaired by placing a concrete block, weighing some 90 tons, in the angle between the breakwater and the spur, and at the same time reducing the depth of water outside to 12 feet by filling in broken stone.

In 1892–93, however, though the concrete block protected the lower portion of the work, the upper portion to 5 feet below water was carried away for a length of 20 feet, and this breach was being repaired by filling in three 90-ton blocks of concrete—two being already in position—when the whole of the side of this 35-foot section of the original work was loosened by a gale, and it was decided to entirely reconstruct the damaged portion.

The same construction was adhered to, but was much stiffened, and a new crib 35 feet square and 14 feet deep was commenced in August, 1894. It consisted of a solid timber bottom of 12-inch by 12-inch hemlock baulks, with 8-inch by 12-inch oak posts on each side of the cross-ties, and 12-inch by 12-inch intermediate posts, all solidly bolted together. The sides and cross-ties were of 12-inch by 12-inch white pine, the upper six courses on the exposed face being of white oak, and the superstructure, of similar construction, was carried thirteen courses above water. The weight of ironwork used, 60 per cent. of which was bolts, averaged 223 lbs. per 1,000 feet (board measure) of timber used. The proportion of ironwork used in former constructions was as follows:—In 1876, with no vertical posts, 89 lbs. of iron was used per 1,000 feet, and of this only 1½ per cent. was bolts, the greater part being spikes. In 1884, 136 lbs. of iron per 1,000 feet of timber was used, and no

[1] The original is in the Library Inst. C.E.

bolts. In the shoreward construction in 1887, which has not yet wanted repair, vertical posts were used, and 157 lbs. of iron per 1,000 feet of timber, 22 per cent. being bolts. The spur built in 1889, which has not suffered in any way, averaged 150 lbs. of iron per 1,000 feet of timber, 75 per cent. being bolts, and vertical posts being used; while the 1890 superstructure, which also has not been damaged, averaged 162 lbs. of iron per 1,000 feet of timber, 78 per cent. being bolts.

The crib was completed on the 26th September, and on the 7th October the removal of the old work was begun, the concrete being broken up with dynamite, and the under-water work dredged out. Owing to rough weather, it was not until the 19th October that the site was cleared, and the same night the new crib was placed in position and filled up to the water-line. The third of the crib next the lake face was filled with large blocks of limestone (obtained from an abandoned mole constructed in 1837), weighing from 1 ton to 5 tons each, the remainder being filled up with loose stone in fragments weighing from 12 lbs. to 200 lbs. each. The parapet and work above water were also formed with these large blocks, and the upper 2 feet of the crib was paved right across with them. The new work was not secured to the old until it had been allowed to settle under the action of a heavy gale. This occurred on the 1st November, and caused a settlement of 2 inches, after which the bonding proceeded as rapidly as the weather would allow. This bonding was extended on each side of the new work so that when finished the new portion was 102 feet long on the parapet, and 63 feet long on the banquette. The whole work was completed on the 3rd December, and has stood well since.

Owing to the confined space and heavy weather, progress was necessarily slow, and great watchfulness was necessary to prevent men being washed away. Oil was used occasionally to prevent the waves breaking, while one great cause of delay was the necessity of making all safe every night, or whenever work was stopped—even after perhaps only an hour's work—a great deal of this temporary work being pulled out again next morning.

In 1884 the Author took some interesting records during a north-west gale. The wind had a recorded velocity of 78 miles per hour; waves at a distance of 1,000 feet from the breakwater moved at a speed of from 34 to 40 miles per hour, the solid crests being 19 feet above normal water-level, and the trough 12 feet below, or a total height, exclusive of foam crest, of 31 feet; while a dynamometer, fixed at a height of 8 feet above normal water-level, registered a pressure of 940 lbs. per square foot. Waves raised by a 20-mile breeze came over the 13-foot parapet of the breakwater with sufficient force to carry away men and material, while those caused by a 60-mile gale threw up dense columns of spray to a height of 120 feet.

The total cost of this reconstruction, which had been estimated at £2,000, amounted to £2,155, of which sum labour absorbed £1,163,

the 119,500 feet (board measure) of timber employed cost about £466, hire of dredger, tug and lighters, amounted to £294, stone for ballast to £120, the 12 tons of ironwork to a little over £100, the balance being made up of various smaller items, such as tallow, oil, &c.

A map of the harbour, showing the breakwater, accompanies the report.

R. B. M.

The Extinction of Torrents in France by Tree-planting.[1]

By P. Demontzey.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 870.)

The Author, in a note, describes the scope of his recently published book on this subject. The work of tree-planting on the French Alps and on the Pyrenees was begun in 1863, and as a result a large number of torrents, which formerly did much damage, have been brought under control.

G. J. B.

Experiments on the discharge of a 30-inch Stop-Valve.

By J. Waldo Smith, Assoc. M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, September, 1895, p. 235.)

These experiments were made with a 30-inch stop-valve on the outlet pipe of a storage reservior built by the East Jersey Water Company for the City of Newark, N.J. On the reservoir side of the valve was an 8-foot length of 42-inch pipe and a pipe 9 feet long, tapering from 42 inches to 30 inches diameter, and on the outlet side a pipe tapering from 30 inches to 42 inches, the same length as before, and a piece of 42-inch diameter straight pipe 4 feet long. The slide of the valve had two parallel faces $6\frac{1}{2}$ inches apart.

For measuring the discharge, a weir with bevelled lip, above the level of the top of the outlet pipe, was fixed on the outlet side. The head above it was measured by a hook gauge. The channel of approach was the same width as the weir, and its sides were of planed matchboard. The discharge was calculated by means of Francis's formula, $Q = 3{\cdot}33\ l \cdot h^{\frac{3}{2}}$; where Q is the quantity discharged in cubic feet per second, l the length of the weir in feet, and h the head above the crest in feet.

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[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 313; vol. lxxii. p. 485; vol. lxxix. p. 407; vol. cii. p. 356. Mr. Demontzey's book, referred to in this Abstract, is also in the Library Inst. C.E.

The following Table gives, in the last column, the loss of head caused by the valve at various stages of opening, calculated by deducting the loss of head in the lengths of pipe connected with the valve, from the total loss of head as given by the difference of the height of the water in the reservoir and at the weir :—

Ratio of Height of Opening to Diameter of Valve.	Area of Opening in Square Feet.	Discharge in Cubic Feet per Second.	Total Loss of Head in Feet.	Computed Loss of Head in Valve alone in Feet.
0·39	2·29	49·30	10·81	9·87
0·29	1·68	36·35	10·95	10·44
0·19	1·07	24·10	11·13	10·92
0·10	0·45	11·75	11·37	11·32
0·03	0·09	4·35	11·58	11·57
0·11	0·51	12·10	11·38	11·32
0·24	1·33	29·15	11·08	10·76
0·37	2·15	45·02	10·93	10·14
0·04	0·15	4·25	9·78	9·77
0·12	0·57	12·40	9·51	9·45
0·22	1·21	24·08	9·34	9·13
0·32	1·82	35·25	9·20	8·71
0·42	2·44	47·00	9·10	8·24
0·51	2·97	59·50	8·94	7·56
0·61	3·51	76·95	8·75	6·45
0·71	3·99	97·05	8·58	4·89
0·81	4·40	123·25	8·33	2·40
1·00	4·90	145·95	8·20	0·00
1·00	4·90	125·00	6·18	0·00
0·84	4·52	74·25	2·67	0·52
0·75	4·18	62·30	2·77	1·26
0·91	4·74	78·95	2·61	0·19
1 00	4·90	81·15	2·58	0·00

A. W. B.

Sixty-inch Steel Conduit for the Allegheny Waterworks.

(Engineering News and American Railway Journal, vol. xxxiv., 1895, p. 234.)

A new intake has recently been constructed on the Allegheny river at Montrose, in order to give an improved water-supply to Allegheny City, Pennsylvania. From the pumping-station the water is forced through a steel conduit 5 feet in diameter for a length of nearly 10 miles to the already existing distributing reservoir. The delivery capacity of the pipe is 50,000,000 gallons per diem, and the work is performed by three compound condensing pumping engines. The trench is partly through rock, partly soft ground, but mostly in sandy gravel.

The pipe is made of soft steel of the following specified quality, viz., ultimate tensile strength, minimum = 55,000 lbs. per square inch, and maximum = 65,000; elastic limit = 32,000 lbs. per square inch; elongation = 25 per cent. longitudinally and 22 per cent. transversely; reduction of area at fracture = 50 per cent. The circular seams are single-riveted, and longitudinal

seams double-riveted. The pipe was made up in the shop in lengths of four courses, alternately overlapping; and in curves, vertical or horizontal, the maximum divergence in any one seam is $2\frac{1}{2}°$. All edges and bevels are planed, and the pipe is caulked at all seams and joints inside and outside, the work having been done by a pneumatic caulking machine, delivering about 10,000 blows a minute. The rivets in the shop-work were inserted from inside, and formed by steady hydraulic pressure of 65 tons on each rivet. For *in situ* riveting up of pipe-lengths, the heading up of the rivets was done under pneumatic pressure from outside.

The following are the general dimensions:—

Mean diameter of pipe	60 inches.
Thickness of plates	$\frac{1}{2}$ inch.
Width of all plates	$73\frac{1}{2}$ inches.
Diameter of rivets	$1\frac{1}{8}$ inch.
No. of rivets per circular seam	66
Pitch of rivets in large ring	2·925 inches.
„ „ small ring	2·879 „
Lap of plates in circular seam	$3\frac{1}{2}$ „
„ „ longitudinal seam	$5\frac{1}{4}$ „
Pitch of rivets	4·617 „

Each completed length of pipe, weighing on average about 8,600 lbs., was tested by hydraulic pressure to about 100 lbs. per square inch, any defects in the caulking being made good under pressure; and the pipe was then immersed in a vertical cylindrical bath, 6 feet diameter, and 25 feet deep, containing a mixture of Sabin asphalte and oil, maintained at a temperature of about 220° F., by means of a 30-inch diameter central steam-drum. After this it was removed to a drying oven, where it remained for five or six hours in a temperature from 350° to 400° F.

The pipe line when laid and completed was tested in 1,000-foot lengths by hydraulic pressure up to 115 lbs. per square inch. This represents approximately the working pressure at the pumping-station end; the pressure gradually decreasing to about 25 lbs. at the reservoir end. The total weight of pipe is about 8,500 tons. Very little is laid on the straight, and expansion and contraction are provided for in all the curves.

P. W. B.

Report on Anderson's Revolving Purifiers and Filtration Experiments at Agra.[1] By S. Crawshaw, Municipal Engineer.

In an introductory note to this report, Mr. C. Perrin, the Superintending Engineer, refers to some experiments undertaken at Agra by the Author, with a view to determining whether it was not possible to procure a better description of sand for filtering purposes, the local Jumna sand being very inferior. The Author

[1] The original is in the Library of the Inst. C.E.

was therefore directed to prepare an experimental filter in order to compare the Jumna, Utangan and Chambal sands as filtering media. He was also instructed to ascertain what benefit was derived from the use of Anderson's revolving purifiers. Tests of the various sands were accordingly made, and the results obtained are given in Tables; the experiments tend to show—

(1) That the Utangan nadi sand, though an excellent filtering medium, is unsuitable, owing to its density and the consequent slowness of filtration through it.

(2) That the Chambal sand is, both with and without the revolvers, much superior to the Jumna sand now in use.

(3) That the effect of the revolvers with slow filtration is not very marked, and that, to get the full benefit of the process, the rate of filtration must be increased.

(4) That no deterioration in the quality of the water results if the head on the filters is increased gradually to as much as 9 inches.

It is pointed out by Mr. Perrin that the Revolving Purifier Company maintain that the rate of filtration, after treatment with iron, should be not less than 70 gallons per square foot in twenty-four hours, but with Jumna sand the requisite head to attain this rate would, in all probability, cause the formation of "blow-holes." It might be possible, however, to obtain this rate with Chambal sand, under a head of less than 6 inches, and thus to satisfy the most favourable working conditions.

In the account which follows of the Author's experiments it is stated that the filters used were 200 feet × 100 feet, formed of two layers of bricks, 3 inches of broken stone, 9 inches of Chambal sand, and an average thickness of 1 foot 7 inches of Jumna sand. The experimental filter was 10 feet × 10 feet, formed of two layers of bricks, 3 inches of broken stone, 9 inches of Chambal sand, covered in the first part of the experiment with 1·8 foot of fine sand from the Utangan nadi, and in the second part with 2 feet of Chambal sand. The purifiers in use were three in number, 14 feet 3 inches long × 5 feet in diameter, with a net capacity of 1,689 gallons. They were each charged with 2 tons of iron punchings. The average rate of contact was three minutes, and the quantity dissolved was $\frac{1}{8}$ grain per gallon. The average head on the experimental filter with the Utangan sand was 4 feet 11 inches (*sic*, should be 4·11 inches), filtering 14·41 gallons per square foot of filter against the old filters with 3·23 inches of head and 37·67 gallons per square foot of filter, or 3·5 gallons per inch of head in twenty-four hours against 11·66 gallons per inch. With the Chambal sand the filter ran thirteen days without stopping, while the old filters were changed twice in the same time. The average head being 1·14 inch, filtering 38·55 gallons per square foot, against 2·86 inches and 37·66 gallons per square foot in twenty-four hours, or 33·73 gallons per inch of head as against 13·15 gallons with the Jumna sand. The purification varied but little from the normal when using Chambal sand, but the Utangan

sand gave better results than those formerly obtained with Jumna sand. Some experiments were subsequently made with revolving purifiers, which show a greater rate of efficiency than was possible with simple sand filtration. A series of chemical and bacteriological tests were conducted by Mr. E. H. Hankin, and full details of them are given in Tables in an Appendix, while the general bacteriological results are set forth and contrasted by means of a graphic diagram.

G. R. R.

Investigations respecting the Pollution of Wells by Water entering from the Bottom. By Dr. E. Pfuhl.

(Zeitschrift für Hygiene, vol. xxi., 1896, p. 1.)

It is pointed out that increased attention is being directed to the necessity for preventing the access of impurities to the surface and the sides of wells. This can best be accomplished by the use of iron tube-wells, but in certain instances it is practicable in shaft-wells so far to exclude the water that it enters only at the bottom, as is the case in the wells which supply Strassburg, Colmar and other towns. The question arises, however, whether it is possible that wells which are properly sealed up at the top and have impermeable walls may become infected with bacteria through the agency of the subsoil water, rising from below, though even in very porous soils it is a matter of experience that only the upper layers become polluted, and infectious germs can therefore only reach the deeper-lying strata exceptionally, as for instance when cesspools are excavated to a considerable depth. In sinking a well, it is not usual to rest contented with the first spring of surface-water encountered, which generally becomes speedily exhausted, but to seek to reach water at some greater depth. Further, it is well known that in water-bearing strata the tendency is, after prolonged pumping, for the level of the water to sink in the vicinity of the well, and a diagram is given from the work of Dr. Krieger to show what took place in the case of a water-works well of Strassburg, from which water was pumped at the rate of 1,540,000 gallons per diem. The water-level in the surrounding subsoil was ascertained by means of a series of Norton's tubes, in the vicinity of the shaft in which the pumping was carried on. The total depression, which was at first as much as 51 inches below the normal level in the soil, in close proximity to the well, became gradually less and then amounted only to 47 inches. It was found that a considerable quantity of fine sand was conveyed into the well. At the end of fourteen years the total depression only reached 23 inches, the explanation being that the constant flow of water had washed out the finer particles and ultimately rendered the soil much more porous, thereby enabling the water to flow into the depression caused by pumping with

greater rapidity. It becomes a question whether the inflowing surface-water in cases of a similar character can by any means be drawn down by the pumps, but experts and authorities who were consulted were unable to throw any light upon this point. The Author therefore decided to investigate this action by means of laboratory experiments, and he accordingly prepared sample soils through which he could artificially pass a stream of water at any desired velocity of flow. Into the soil he sank a well which was represented by a 6-inch iron pipe, and from this well water was drawn at a given rate by means of a glass tube and a siphon formed of india-rubber tubing. The arrangements made in selecting and composing the soil, and in ensuring a uniform flow of water through it, are described, and the surface of the water-holding miniature gravel-bed was then infected with bacteria, a culture of the *micrococcus prodigiosus* being selected for the purpose. In a very few minutes the water drawn from the well contained specimens of the bacteria. Samples were taken at intervals of three, six, ten, thirteen, twenty, thirty, thirty-five and sixty minutes after infection and cultivated in the usual way on gelatine. The results obtained are set forth in tables. Various sets of experiments described by the Author, to the number of eight in all, were undertaken, and he states in conclusion that in highly porous soils, such as those represented by his artificial tests, as soon as the upper layers of the soil are infected with germs, wells which contain impervious linings are liable to be invaded by these organisms, even when the tube or lining passes considerably below the zone which contains the infecting matter.

G. R. R.

The Municipal Gasworks of Berlin.[1]

(Gesundheits-Ingenieur, 1895, p. 279.)

Attention is directed to the diminished consumption of gas in Berlin in 1893–94, due partly to commercial depression, but also to the increasing use of gas-economising burners and electric light. Efforts have been made in various ways to increase the use of gas, to reduce the price, and to utilize the by-products. The total quantity of gas manufactured was about 11,750,000 cubic feet in excess of the previous year's total, but does not attain to that of 1891–92. In 1892–93 the decrease in the production of gas exceeded 35,000,000 cubic feet. Gas used otherwise than for illuminating purposes shows an increase of more than 28,250,000 cubic feet, but for the lighting of private houses there is a falling off of upwards of 35,000,000 cubic feet. In some of the older parts of the town there is an increase in the consumption, but in certain

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 365.

other quarters the diminution reaches as much as 18·9 per cent. The English company's works show a total decrease of 1·48 per cent., while in the municipal works the decrease is only 0·61 per cent. for the twelvemonth. A statement follows of the number of electric-lamps and gas-lamps in use. Assuming one arc-light to be equivalent to six glow-lamps, and each glow-lamp and motor to be equal to one gas-jet of 16 normal candles, the electric lighting establishments represent 155,967 lamps and the private institutions 104,766 lamps. The former show an increase of 18·4 per cent. over last year, and the latter an increase of 13·2 per cent. In March, 1894, the municipal gas companies supplied a total of 925,120 private lights, and there were electric lights equivalent to 260,733 burners. The financial results, an analysis of which follows, were less favourable than those of the previous year. The amount of gas unaccounted for in the municipal establishments is less than in any former period and amounts to only 4·49 per cent. of the entire production. If the loss of gas is about the same in the works of the English company, the Imperial Continental Gas Association attained a total production of 1,177,000,000 cubic feet, as against 3,630,000,000 cubic feet distributed from the Municipal Works. Gas was supplied to 1,123 gas-engines with a total of 5,145 HP. The smallest quantity of gas used in twenty-four hours, as compared with the maximum quantity in the same interval was as 1 : 5·57. The largest quantity used in twenty-four hours, as compared with the total for the year, was as 1 : 203·66; the highest quantity supplied in one hour, as compared with the maximum in one day, as 1 to 8·03. This year, for the first time on record, the coal in one of the depots became strongly heated and even ignited. On the evening of the 18th August, 1893, volumes of smoke issued from the coal-heaps in one of the sheds where the total depth of coal was over 26 feet. After five days' work in removing the coal, the fire, which had broken out in three separate places about 2 feet to 8 feet above the ground-level, was reached and extinguished by jets of water. Statistics are given of the amount of coal used for gas, the product per ton, the number of charges in the retorts, the illuminating value of the gas, the length of the mains and the number of burners in street-lamps. The cost of public lighting, which amounted to £127,650 is analysed, the value of the gas being taken at 3*s.* 5*d.* per 1,000 cubic feet. The above total includes the cost of electric street-lighting £6,967, and of petroleum lamps in certain suburbs £2,927.

G. R. R.

Peat-dust Water-closets with Separate Treatment of the Excreta.

By Dr. Z. Koiransky.

(Gesundheits-Ingenieur, 1895, p. 357.)

It is pointed out that the question of the rapid removal of excreta from towns, which is a subject of the utmost importance, is becoming more and more intimately connected with the necessity of providing at the same time a means for making these substances available for agriculture. The conditions which have to be satisfied in dealing with excreta, as formulated by the Author, are:—

(*a*) The abolition of the cesspool, and the tub or pail, in fact, of all receptacles in which the putrefying fecal matters have hitherto been stored.

(*b*) The introduction of special closet apparatus, by means of which the decay of the excreta may be prevented and rendered impossible.

Some recent authorities would add to these the suppression of the water-closet, because the large volume of water employed (from 90 per cent. to 97 per cent.) so vastly increases the difficulty of removal and utilization. The Author's maxim is, however, "No rinsing out of the pan, no cleanliness. No cleanliness no comfort." And his third condition is, "retention of the water-closet, as alike necessary for cleanliness, health and comfort." He has therefore introduced domestic arrangements whereby human excreta and soiled water are at once disinfected, and at the same time converted into a readily portable manure, easily handled and rendered entirely free from smell. This is accomplished by means of apparatus which is explained by reference to a diagram. It consists in the main of a separator-closet, or sets of closets on each floor of a dwelling, combined with appliances in the basement for dusting over the solid matters with powdered peat, and the filtration of the liquids through peat fibre and soot. The water and the liquid dejections pass by a special soil-pipe to the filter, the solids fall through a shoot into a receptacle in the cellar, over which by means of a movable step or footboard in the closet a small quantity of peat-dust is sprinkled at each use of the closet. It is claimed that this apparatus is extremely simple, that it is quite devoid of smell, and that the liquids passing into the sewer, after the filtering process is completed, are freed from all polluting matters. The solids are converted into a dry portable manure. Practical experiments have been for some time in progress at the Ducal Palace in Munich, and it is stated that the experimental closet has been used daily by about twenty persons since the 1st of August. In this period the filter, which is of the capacity of about 106 cubic feet and contains 70 cubic feet of filtering material, has (at the date of writing, October, 1895) not yet given off any liquids. This is probably due to the great power of absorption possessed by the peat. The various considerations which should recommend this process to sanitary authorities are briefly set forth in conclusion. G. R. R.

The Municipal Station for the Burning of Refuse in Berlin.

(Annalen für Gewerbe und Bauwesen, Dec. 1, 1895, p. 209.)

Attention is directed to the large area of waste land outside the Stralau Gate, where the experimental works are in progress for the combustion of house-refuse, and where the heaps of ashes, already deposited, at times give out highly unpleasant effluvia. From certain named collecting places, the Berlin refuse is taken away in boats or barges at a very low rate, and it can scarcely be expected that the total cost of burning the ashes, &c., will fall below these figures. The question rather is, how much will the community be willing to expend in excess of this amount in order to have the refuse dealt with in a more satisfactory manner than the system now in vogue of collecting it into vast mounds in remote suburbs for future removal? Experiments are in progress at the present time in many English cities in burning the ashes and house-refuse, and information and statistics on the subject have been collected on the spot by Mr. Grohn and Mr. Bohm. An account follows of the two sets of test-cells, three of each, on the systems of Warner and of Horsfall, recently erected at Berlin.[1] In the former, from 3 to 4 tons of refuse can be dealt with daily, but a special fire is needed in the flue to consume the foul gases given off in burning and drying the refuse. Horsfall's cell avoids this second fire, by taking the hot gases direct from the combustion-chamber into the chimney; but in order to render the heat sufficiently intense in the fire-chamber a forced draught is required. In England this is obtained by means of a steam-jet, and in the Berlin trials steam to the amount of 165 lbs. per cell per hour was at first employed for this purpose, but a pressure-blower was subsequently made use of, and the daily yield per cell then rose to 6 to 7 tons, which is about the average in England. The intention was originally to insert a boiler into the flues and thus to procure the requisite steam, but with the Berlin refuse the flue-temperature was too low for this purpose. In fact it has only become possible after prolonged trials in these experimental works to accomplish the combustion of the ashes without the added fuel which was at first needed. The results so far appear to be encouraging, for the refuse is converted into clinkers and ashes free from all smell. Details are given of the composition at the different periods of the year of the refuse collected, and the figures are compared with those observed under similar conditions in England. In Berlin the residue from the destructors amounts to no less than 50 per cent. of the total weight of the refuse, while in England it varies from 25 per cent. to 33 per cent. The question of the utilization of the residual substances, even in England, where the subject has been under

[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 443.

consideration for many years, has not as yet received a satisfactory solution. In a few cases the clinker is used for mortar, but at Liverpool it is regularly thrown into the sea. It is anticipated that it may be possible in the case of Berlin to dispose of even the winter-collected dust without the previous separation of the fine ashes by means of sifting, as has been necessary hitherto, but the process cannot even thus be deemed wholly satisfactory from the point of view of cost.

G. R. R.

The Railway System of Japan.

By Charles A. W. Pownall, M. Inst. C.E., Engineer-in-Chief Japanese State Railways.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, 1895, p. 409 *et seq.*)

The Japanese Empire comprises a number of islands, of which the four principal are Yesso, Nippon, Shikoku and Kiusiu, the respective areas of which are approximately 20·6 per cent., 58·9 per cent., 4·7 per cent., and 9·4 per cent. of the total. Nippon, the largest of these islands, has a length of about 870 miles, and an average width of somewhat less than 90 miles; a central range of mountains, from 6,500 feet to 10,000 feet in height, extending throughout, and confining the population mainly to the valleys and the coast line. Of the total area of the empire (149,153 square miles), scarcely 12 per cent., or 17,443 square miles, can be described as cultivated area.

The whole details of railway construction, equipment, and working have been quickly learnt by the Japanese people. The first line, from Tokyo to Yokohama, was opened in 1872, when there were about 200 Europeans in the Japanese railway service. In 1882, when the Author came to Japan, the number was reduced to twenty-one; and at the present moment there remain only six. The first line constructed by a private company was in 1881, from Tokyo to Aomori, a distance of 443 miles. At the end of 1893 the total length of State railways opened was 549 miles, and in construction 422 miles; and private companies' lines open 1,317 miles, and in construction 552 miles. The Tokyo and Yokohama line is double, and cost, including the large workshops, on an average £16,000 per mile. All the other lines are single, and the average cost has been £7,200 per mile; while those now in course of construction, mostly through level country, average £3,200 per mile.

The rivers flowing across the plain from the mountain region to the sea form a peculiar feature in the topographical character of the country. They bring down an immense quantity of alluvial matter, so that the channels are gradually silted up; and as this develops, dykes are constructed on each side to protect the adjacent

country. As the bed is more and more silted up, the dykes are correspondingly raised; so that it is not uncommon for the bed of a river to be more than 30 feet above the level of the surrounding country. As the trunk-lines traverse a number of these raised rivers, the alternative is presented either of constructing a viaduct with long approaches and high piers through the silt down to firm bed, or of tunnelling through the pervious mass. The former method is generally preferable. Generally speaking it is advisable also to restrict the width of the channel by piers as little as possible, on account of the liability to flooding. In comparing the two systems of short and long spans, on a bridge say 1,000 feet long, with piers 26 feet above the river-bed and 72 feet below the ground surface, the former consisting of 40-foot span plate girders, and the latter of 200-foot span lattice girders, the following results express the relative advantages:—

(1) Cost—	£
Lattice-girder bridge	14,593
Plate-girder bridge	8,061
Being in favour of latter . . .	£6,532

(2) Diminution of width of channel—	Feet.
In lattice-girder bridge	50
In plate-girder bridge	119
Being in favour of former	69

The general preference has been given to large spans over the main channels, the standard type in recent structures being 200 feet span. The girders were formerly of wrought-iron, but recently steel has been adopted. The following list shows the ten more important railway bridges erected up to the present time in Japan:—

No.	Site of Bridge: over River:	Line—Single or Double.	No. of Spans.	Spans.	Total Length.	Height of Piers.	Total Weight of Metal.	Material.	Total Cost.
				Feet.	Feet.	Ft. Ins.	Tons.		£
1	Kansaki	Single	13	94	1,297	13 6	739·7	Wrought-iron.	28,341
2	Rokugo	Double	24	40	1,650	21 0	922·6		43,491
			6	94					
3	Toda	Single	4	94	3,037	22 0	849·2		17,620
			48	50					
4	Tone	,,	3	200	1,530	18 0	1,051·0		22,000
			9	94					
5	,,	,,	5	200	1,055	26 0	898·0		18,154
6	Nagara	,,	5	206	1,490	25 6	1,125·6		20,427
			4	94					
7	Kiso	,,	9	200	1,874	31 0	1,616·4		30,229
8	Tenriu	,,	19	200	3,967	18 0	2,954·0	Steel.	50,705
9	Oi	,,	16	200	3,339	16 0	2,488·0		40,922
10	Fuji	,,	9	200	1,874	28 0	1,400·0		28,236

In Nos. 1, 2, 3, 4, 5, and 7, the piers consist each of two cylinders filled in with brickwork; in No. 6, on account of the excessive liability to flood, groups of five piles, each 2 feet 6 inches diameter, were adopted. In Nos. 8, 9 and 10, single elliptical piers were constructed, the major and minor axes being respectively in Nos. 8 and 9 24 feet and 12 feet, and in No. 10 35 feet 6 inches and 18 feet.

Railway construction in Japan has to contend with one special phenomenon: the liability to continually recurring earthquake shocks, sometimes slight and sometimes serious. A severe series of earthquakes occurred in 1854–5; after this, with the exception of 1872, there were no further serious disturbances till 1885. The special experiences of severe shocks had been almost forgotten even by the native population, and although the neighbourhood of Tokyo was always considered somewhat uncertain for stability, other districts caused little concern, and no special precautions were taken in railway construction. On October 28th, 1891, however, a very severe earthquake occurred, which, in the space of a few minutes, destroyed 197,947 houses, and caused serious damage to the railways, sixty-three bridges being more or less dislocated or thrown down. The Author shows by several photographs some of the more striking aspects of the damage thus caused; such as the bridge over a street at Nagoya, entirely in ruins, and the railway embankment between Nagoya and the Kiso, the rails being twisted into a serpentine series of distortions. In the Kiso bridge itself the girders were not much damaged, but the whole superstructure was shifted laterally about 3 feet, and the piers were thrown out of their vertical position to the same extent, and more or less damaged. All the piers had to be replaced. The bed of the river had been compressed to the extent of about 1 per cent., and the piers were correspondingly distorted. At the Nagara Bridge the approach embankment entirely disappeared, leaving the permanent way hanging in mid-air. Most of the piers of the bridge were destroyed, some vanishing entirely, and the spans collapsed and were displaced laterally about 20 feet. The earthquake originated in the upper portion of this river basin, and the shock was especially severe throughout its length. The large girders were, however, not appreciably damaged, and were re-erected on single elliptical piers. The total cost of repairing the damage on the railway was £47,000.

The rolling-stock equipment was derived from various sources. In Yesso the first locomotives came from America. In Nippon about twelve were American, four are of German manufacture (Abt system) and the rest English, with the exception of a few that have been built in Japan. The number of engines on the State railways in Nippon in 1894 was 140, and on private lines 142. The passenger carriages are all either English or built in Japan after the English model. In Kiusiu the rolling-stock is all German.

The average equipment per 100 miles is as under:—

Locomotives	18·84
Passenger carriages	65·20
Goods-wagons	283·40

In 1870 the gauge was fixed at 3 feet 6 inches, but it has since been a constant matter of regret that the 4 feet 8½ inches standard was not adopted.

Most of the locomotives are four-axle, three-coupled, and weigh in full working order 45½ tons. They work over gradients of 1 in 40, and can haul a load of 138 tons at a speed of 12 miles an hour. The newest type of carriages has a length of 46 feet 9 inches. All the vehicles are fitted with air-brakes. The whole of the rolling-stock on the State railways is kept in repair at the work-shops at Tokyo and Kobe, which are well equipped with all machinery and appliances, and employ about 2,000 men. In addition to the maintenance work they are capable of turning out 120 passenger carriages and 480 goods wagons per annum.

The average fare (corresponding to third class) is about ¼*d.* per mile, and the working expenses on the State lines average 47 per cent. of the gross receipts. On the private lines the average is rather higher.

P. W. B.

The Consolidation Works of the Sceaux Railway Extension in Paris. By O. Keller.

(Annales des Mines, vol. viii., 1895, p. 125.)

In April, 1895, there was opened for traffic an extension of the Sceaux Railway from the old terminus to the Carrefour de Medicis close to the Luxembourg. The line, about a mile in length, which is nearly all subterranean, has been constructed on the cut-and-cover system, with an arched roof, except in places where the cover is insufficient, when a metal roof is used. The abutment walls, tapering in thickness from 1·56 metre below to 1·4 metre at the top, stand upon a base 2 metres wide upon the ground; as the proposed invert in masonry has been found to be unnecessary, except for about 300 metres on wet clay-beds, the remainder being dry stone. A bottom culvert collects the drainage-water which falls by absorbing wells to the natural water-level of the Seine. The tunnel is 9 metres wide along the line and 16·8 metres at the terminal station where the walls are 3 metres thick; the headway in the centre is 6 metres. The thickness of the arch at the crown is 0·65 metre; the whole of the masonry being done in burr-stone rubble set in Portland cement mortar. The line is laid on a falling gradient of 1 in 63, with a short piece of 1 in 48 at the junction with the old station, and reduced to 1 in 250 and 1 in 300 in the new stations.

The shelly freestone bed, known as the *Calcaire grossier*, occurring below the line, at depths varying from 18 to 26 metres, has been mined for building stone to such an extent as to render consolidation works necessary over more than half its length, the hollows occurring in three groups separated by two masses of solid stone. The former are respectively 234, 131 and 511 metres long under the railway, or 896 metres in all, in addition about 60 metres in a lower series of workings and 43 metres on a parallel side line were forced to require support during the execution of the works.

The thickness of the stone removed averages about 3 metres in the upper and 3·2 metres in the lower workings, there being a bed of 1·25 metre between them. In the latter, supporting pillars, from 4 to 6 metres in the side, have been left, which, although much fissured and crushed in places, are not destroyed; but in the upper series the whole of the stone has been taken out and the hollows filled with the waste produced in stone-dressing, more or less compressed by subsidence of the roof, with some pack walls and pillars built of dry stone. The consolidation, however, is not sufficient to form a safe foundation for masonry, and specially dangerous places from the formation of bell-pits (*cloches de fontis*) were found to be very abundant in one of the sections.

The strengthening works consist of lines of walls under the footings of the tunnel walls, built in pairs, and enclosing a longitudinal inspection gallery 1 metre wide; the total breadth under each side being 2 metres, which is sometimes evenly divided and sometimes one of the gallery walls is made thicker than the other, the range being from 0·6 to 1·4 metre. The inspection galleries are united at variable distances from 28 to 40 metres by cross drifts, also walled and arched. In places where the rock forming the floor is soft, the walls are carried upon arches of 1·8 metre opening, springing from piers 1·2 metre square, built in pits 2·15 metres deep. At the north end of the line, where there were very extensive falls of roof, the supporting walls are thicker to a total of 2·4 metres, and pillars of 1 to 1·2 metre by 3 metres long are built along the axis of the tunnel, which is also supported by walls at the crossings of the old quarry roads, the hollow places being filled with earth beaten hard and strengthened by dry stone walls.

The most difficult and troublesome part of the work was the securing and filling of the bell-pits, to the number of nineteen, traversed by the line. These, as shown by the Author in a former Paper,[1] are produced by the gradual falling away of the softer shale above unsupported places in the quarry roof, producing a chamber usually of an elliptical form, with a domed or funnel-shaped roof which continually increases in height, sometimes causing the surface to fall in.

When it is merely desired to consolidate the surface for a road, the hollow may be filled by sinking a pit to meet the apex of the roof and throwing in earth slightly wetted to make it bind; or,

[1] Minutes of Proceedings Inst. C.E., vol. l. p. 199.

what is a better method if the bell-pit is accessible from below, to clear it out and fill it up with dry stones regularly arranged in steps. When, however, buildings are to be placed on the ground, semi-liquid concrete is poured down a surface pit upon the fallen stuff to consolidate it, and the bell and pit are afterwards filled with ordinary concrete. A similar but more complete method is to sink the pit through the rubbish to the solid floor of the quarry and fill it with concrete so as to obtain a pillar on a firm foundation. The last and best method of all is to clear out the pit, line it with a wall up to the roof, and finally fill it up with stone and mortar masonry. Applications of each of these methods were made in the nineteen bell-pits traversed by the line.

The work done in the lower quarries consisted in building heavy longitudinal walls and buttressing the broken pillars and lining a bell-pit passing through both sets of workings, packing the hollow spaces with earth or dry walls. Access for inspection is obtained by a stone staircase from the upper level.

The works were done by contract under the supervision of the Municipal Quarry Inspection Department at the charge of the Paris and Orleans Railway Company. The total amount of masonry, most of it being done with burr stone brought from the Yvette quarries by railway, was 7,636 cubic metres, including the 1,306 metres used in the work in the lower bed. The mortar contained 350 kilograms of hydraulic lime in powder to 1 cubic metre of sand. The cost for building alone being 21 francs per cubic metre, the total cost was 490,867 francs (£19,634 14*s.*), corresponding to 64·28 francs per cubic metre.

The subterranean quarries in Paris are very extensive. The area undermined, according to the latest investigations of the Author, is nearly 10 per cent. of that of the entire city, or 1,905 out of 19,278 acres, and the total length of galleries still accessible is about 80 miles. Building stone has been quarried on both sides of the Seine, but principally on the left bank; while the gypsum quarries are confined to the right bank.

H. B.

Slip at a Summit Tunnel in California. By J. D. Isaacs.

(Journal of the Association of Engineering Societies, New York, September, 1895, p. 113.)

The tunnel in question is on the Santa Cruz division of the Southern Pacific Railway (commonly called the narrow gauge), and is known as Wright's Tunnel. It is 1·16 mile long, and for some 200 feet from the northern end is driven through a clay stratum resting upon a rock bed inclined northwards towards Los Gatos Creek. The maintenance of this tunnel has always given trouble during winter storms, for which this part of the country is remarkable, but no serious impediment to traffic occurred until the winter of 1892–3.

The railway crossed over a side creek at the mouth of the tunnel, which joins another creek a few feet away from the railway. In the heavy storms of 1892–3 the two creeks cut through the clay bed to the rock below, and the whole hillside for some 300 feet back slided forward. The tunnel was crushed in, and traffic was completely stopped, and could not be resumed until dry weather set in. As it was evident that some means would have to be taken before the ensuing winter, in order to prevent slipping, it was eventually decided to re-establish and maintain the toe of the slide by raising the beds of the two creeks, and by constructing a concrete retaining wall or dam, pierced by the tunnel, between the rock points on each side of the railway. The side creek was thus carried over the tunnel and behind the wall, and joins the other creek, the combined streams discharging through the wall by means of a tumbling bay.

As the new tunnel cut through the slip, it was necessary to transmit its thrust from south to north. The sides were therefore carried down to the rock, and an invert was put in. The new portion of the tunnel is 200 feet in length, and is elliptical in shape, the extreme width being 19 feet, the thickness of the arch-ring at the crown 2 feet, increasing to 4 feet at springing level, and the height above rail-level at the crown 20 feet. The tunnel was loaded with earth from 15 feet deep at a distance of 42 feet from the retaining wall to 25 feet deep at its further end.

The whole of the work was constructed of concrete, mixed in the proportion of two parts of sand, three parts of gravel, and four parts of broken rock passing through a 2-inch ring, to one part of Portland cement. The concrete under rail-level, with the exception of the invert, had large pieces of rock imbedded in it, varying in volume from $\frac{1}{4}$ to 1 cubic yard. They were regulated as follows: a layer of concrete 6 inches thick was first laid, then large pieces of rock, with their best bed down, usually standing on one of their ends, were imbedded, with clear spaces of about 18 inches between them, into which concrete was carefully rammed. Whenever there was room enough, smaller stones were thrown in and rammed with the concrete, care always being taken to surround the pieces of rock with concrete. One course having been built in this way, the same method was pursued until rail-level was reached.

The retaining-wall, 180 feet in length, is about 28 feet high above rail-level, and is 14 feet thick at and below this point, and 2 feet thick at the top. The entire work contained about 4,000 cubic yards of concrete, which, exclusive of moulds, cost 24*s.* per cubic yard; the moulds would add 20 per cent. more. The work was completed in six weeks, and up to the present the structure shows no cracks or other signs of failure, and is apparently good for permanent endurance. The Author also describes the arrangements for mixing the concrete.

Plans and sections of the tunnel and retaining-wall are given.

J. A. T.

On Iron Sleeper Permanent Way. By J. Schuler.

(Organ für die Fortschritte des Eisenbahnwesens, 1895, pp. 178 and 199.)

In reviewing the descriptions of various forms of iron sleepers which have appeared in the "Organ" during the last year, the Author states that a sleeper, good from an economical point of view, must fulfil the following conditions: firstly, it must ensure a firm fastening of the rail with a sufficient capacity for resistance, and must be capable of being advantageously packed; and secondly, it must secure for the permanent way a firm and fixed position in the ballast. None of the systems at present known fulfils the latter condition, because in consequence of the rigid connection between the rail and sleeper, the sleeper is forced to yield more or less to the forces which act upon the rail, and the amount and direction of the movements of individual sleepers are unequal and variable. A wooden sleeper in bending tends to move in the direction of its longitudinal axis, whereas an iron sleeper has a tendency rather to rotate around its longitudinal axis, which is the most hurtful motion to which a sleeper is subjected, and it is therefore most important that a remedy for it be found.

The Author, by the aid of figures in the text, enters into an analysis of the forces acting on a sleeper, and the conclusions he arrives at are, that iron sleepers with a cross section approaching most nearly to an arc will offer the least resistance to rotatory motion, and one of rectangular form the greatest resistance; those of trapezoidal form cannot be maintained in a fixed position in the ballast. A sleeper proposed by M. Schubert of a form similar to a V, with the centre solid and the tails turned back flat, adapts itself to packing more easily and advantageously than any other sleeper, and is better protected against rotatory motion.

The unstable position of iron sleepers laid in ordinary ballast caused some railway companies to use broken stone for ballast, and although this made a firmer bed with a greater resisting capacity, the rolling stock and rails were subjected to a greater strain in consequence of the diminished elasticity of the formation. Fractures of rails, sleepers, wheels and springs increased on these lines.

The Author states that a complete removal of the difficulty is only possible by using a flexible rail, and not therefore by increasing unnecessarily the weight of the rail; and if, whilst retaining the ordinary spacing of the sleepers and rails, whose moment of resistance is sufficient for the loads, an elastic bedplate is used, by means of which the loads always act at the centre-line of the sleeper, then the latter not only replaces the elasticity of the wooden sleeper but it admits of the introduction of light iron sleepers with a large moment of resistance, of wider surface and capable of being well packed, because in the formation of these sleepers, the moments tending to cause rotation need not be taken

into consideration. An elastic bedplate answering to these requirements was described by the Author in an earlier number.[1] The elastic bedplates reduce the action of the joltings upon the rail supports, and the ballast and rails are maintained much better in position; without increasing the weight or amount of expenditure, a greater security in working, and higher speeds are attained with a reduction of working expenses. The Author is of opinion that the employment of metal sleepers would be materially extended if they were supplied with elastic seatings.

The Papers are accompanied by various sections of iron sleepers.

J. A. T.

The Heating and Ventilation of Passenger Trains.

By Jules Dery.

(Bulletin de la Commission Internationale du Congrès des Chemins de Fer, 1895, p. 3251.)

At the fourth session of the congress it was stated that at the meetings held each year in the United States of America for discussing this question, the following conclusions had been adopted:

"There are only three essential elements of a system of heating by steam, all the others being secondary.

"These three elements are: the coupling, drainage, and the discharging valve.

"The foremost requirement of the coupling is that it be tight: only one joint should be permitted.

"All the water of condensation should drain by its own weight and accumulate in a discharging valve; further, the tubes should be of the same sectional area as the general conduit, both in the carriage itself, and in the connections between carriages.

"With regard to the discharging valve, it should be automatic, allowing a certain quantity of water of condensation to accumulate, and expelling it periodically without dripping continually."

The Author, taking into consideration the type of carriages with compartments generally used in Europe, thinks that the conclusions thus formulated should be supplemented by the following points:

(*a*) The time occupied in the transmission of the steam from one end to the other of the train should be so short that there will be no necessity, before its departure, to have recourse to a means of heating other than that from the locomotive destined to draw the train.

(*b*) The heat evolved in all the compartments should be practically uniform, whatever may be the position of the carriage, either at the front or rear portion of the train.

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[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 453.

(*c*) The engine-driver should have at his disposal a rapid means of discharging the steam contained in the general conduit, for the purpose of facilitating the addition or withdrawal of carriages.

(*d*) In the system of heating employed it ought not to be possible for the cocks to be worked by hand.

(*e*) With the object of regulating the temperature of the compartments, the system of heating should at the same time admit of a process of ventilation, in order to render the surrounding air wholesome.

With a view to combine these requirements the Author has designed the system of which the following is a short description. The general arrangement is known as the "underneath" system, although the "overhead" system could easily be adopted, that is to say, with the general conduit placed near or on the roof of the carriage. An automatic blow-off cock is fixed at each end of the carriage, if the conduit is inclined towards the ends. If only one blow-off cock is fixed, the conduit is inclined towards the centre. The new system is represented as being applied to the old Haag process, with a single reservoir placed under the seat; it is, however, equally applicable to other systems where a series of horizontal tubes is made use of, through which the steam passes. The automatic blow-off cock is on the Heintz system, the essential feature of which is a tube-spring. In its normal position the valve is open, but as soon as the steam begins to pass through the conduit it closes. The appliance being fixed at the lowest point of the conduit, the water of condensation necessarily accumulates there; when the tube-spring is heated to 208° F., that is to say, when the steam begins to pass through, the tube straightens itself and the valve just bears upon its seat. As soon as the steam no longer passes through, the tube-spring, which is filled with a volatile liquid, such as naphtha, becomes cool, takes its first position and discharges the water of condensation which has accumulated above the closing valve. No dripping takes place, but a complete discharge, intermittingly, of all the accumulated water is produced. The temperature of 208° F. has been chosen, but the cocks can be regulated to any temperature varying between 167° and 212° F.

On the general conduit a tube branches off to each cylinder, which is placed under the seat of the carriage. In order to prevent the return of condensed steam through this tube the latter is carried to a certain height above the bottom of the cylinder, and another tube soldered to the bottom at its lowest point (the cylinder, being slightly inclined) takes the condensed steam into a second special conduit, inclined from the ends towards the centre of the carriage, where it is discharged by a blow-off cock.

With the object of controlling the heat developed by the cylinder a regulating appliance is placed under the seat. This appliance consists of a plate-box with a movable lid placed in the interior of the compartment, and in which the cylinder is enclosed, and of two regulators with balance-weights and air-valves placed at the ends of the box. The movable lid is attached, at its two lower

ends by two chains or ropes over pulleys, to the balance-weights. Two rigid rods fixed to the balance-weights enable the lid to be worked from the outside of the carriage. The regulators are of cast-iron with a central rectangular opening which receives the balance-weight moving vertically, and are fixed at the level of the second footboard of the carriage and against the longitudinal bearers. Each regulator is provided with two air-tubes arranged in such a manner that when the balance-weight is at the bottom of its course both tubes are completely closed; when the balance-weight is at the centre of its course one tube only is open; and when at the top both tubes are open. One of the tubes brings the air into the box containing the cylinder, whilst the other opens behind the box directly into the compartment. At the bottom of the regulator there are two symmetrical air-valves, in order always to permit the entry of air in whichever direction the train is travelling. The entry of the air into the regulator is controlled by means of sliding shutters which are fixed at different heights by means of chains, their position being determined by the temperature of the atmosphere. By means of the arrangement adopted the three following conditions are obtained: firstly, heating without ventilation in the case of very low temperatures; secondly, heating with ventilation in the case of low temperatures; and thirdly, ventilation without heating for summer service.

The Author describes in detail the construction of the valves, and states that if required it can be easily arranged that the regulating may be worked by passengers, and gives sketches showing an arrangement of this kind. The appliances on the locomotive consist of a valve on the "autoclave" system, provided with pipes communicating with the general conduit and the steam-gauge, and a safety spring-valve which prevents the steam entering the general conduit with a greater pressure than three atmospheres; to these the Author has added a throttle-valve for the purpose of withdrawing the steam from the general conduit of the train into a special conduit opening in the fire-box or the air. This new arrangement has the following advantages:

1. The carriages can be uncoupled without danger, the driver being able to empty the general conduit before entering a station in which a modification in the composition of his train is to be made.

2. The interrupting cocks at the ends of the carriage are suppressed, and

3. Important stations are prevented from being filled with clouds of steam.

The couplings are also fully described, and numerous sections accompany the Paper.

J. A. T.

Metallic Underframes for Wagons used by the Western of France Railway Company. By J. Morandière.

(Revue Générale des Chemins de Fer, October, 1895, p. 155.)

The Western of France Railway Company have recently brought into use a number of wagons with iron underframes; two types of wagons have been constructed, namely, a covered six-wheeled goods wagon, fitted with a continuous brake, and of large capacity, to be used for special service, and an ordinary wagon 23 feet long, with sides 1 foot 8 inches deep, to carry 12 tons. The tubular system was not adopted because it was considered that underframes constructed out of angle, channel, or tee bars, not only enabled a more rigid frame to be built and simplified the construction, but were also more economical.

In the underframe adopted, the two courses replacing the ordinary side-bearers consist of two channel bars, of $3\frac{5}{32}$ by $1\frac{21}{32}$ by $\frac{5}{16}$ inches, placed $3\frac{9}{16}$ inches apart, one being above the cross-bearers, and the other between them. The two exterior bearers, and the two bearers placed at a distance of $15\frac{3}{4}$ inches from the centre line of the wagon, have one channel bar of the same dimensions above, and an unequal angle bar of $3\frac{5}{32}$ by $2\frac{3}{8}$ by $\frac{5}{16}$ inches below the cross-bearers. Cross-bearers are placed on each side of the wheels, and consist of channel bars lying below each of the channel bars forming the side-bearers, and they are prolonged to the exterior bearers. The sides of the ordinary goods wagon are formed of plates $\frac{5}{32}$ inch in thickness, riveted to vertical channels; the interior width is 9 feet. The weight of this wagon is 6·85 tons, the maximum load it can carry being 12 tons for slow trains and 8 tons for express trains. The Author claims that the number of pieces of forged iron are reduced to a minimum, that the labour in construction is simplified by the use of bar-iron of workable dimensions, cut into lengths and stamped, and no angle is curved or joggled; 700 low-sided wagons of this type are in use on the Western of France Railway.

The covered wagon, which is generally attached to passenger trains, has an underframe constructed similarly to that of the ordinary goods wagon, and is 27 feet long. Its weight is 10·83 tons, and its load varies according to the nature of the trains, namely, 15 tons for slow trains, 10 tons for quick trains, and 8 tons for express trains.

A full description of the details of construction is given, together with three plates.

J. A. T.

Car-Ferries in the United States.[1]

(Railroad Gazette, November 1, 1895, p. 724.)

The New York, New Haven, and Hartford railroad has for a long time worked an extensive system of transferring both freight- and passenger-cars; they have two transfer steamers, the "Maryland" and the "Express," both of which have been described previously in the *Gazette*. The "Maryland" has a capacity for carrying six long passenger-cars or twelve freight-cars, and the "Express" a capacity of ten passenger- or nineteen freight-cars. This company has also ten large tugs and thirty-five floats, the latter having a capacity of ten to seventeen cars each. The "Maryland" is used principally for transferring the Boston and Washington trains from the dock on the Haarlem River to the Pennsylvania station; two of these trains are transferred each way every day. From the 1st January to the 1st September, 1895, the floats transferred a total of 313,262 cars.

The other railways having termini on the waters of New York harbour all operate constantly a large floating equipment for transferring freight-cars between their own termini and their own or other piers in the harbour. The Author states that the capacity and flexibility of this method of handling freight, the cheapness with which it is done, the ease with which cars can be delivered to any point on the water front, the unlimited development of which the system is capable, are all elements which conspire to render any bridge across the North River or any tunnel underneath a superfluity as far as handling freight is concerned. The car-ferries working in New York harbour are subject to no stress of weather except fog, and running ice in winter, but quite a different set of conditions is found in the car-ferry of the New York, Philadelphia, and Norfolk railway running between Cape Charles and Norfolk. The distance is 36 miles, and the floating equipment consists of two steamers, three tugs and four barges. The two steamers do not carry cars, but take the passengers and a certain amount of loose freight. This service has been in operation since 1884, and at that time a transfer steamer for carrying through passenger- and sleeping-cars was used and successfully carried on for a year or two, but was afterwards abandoned because at that time the company had no through connections south of Norfolk. The tugs and barges transfer the freight-cars across the bay; the largest of the barges is 311 feet long and 37 feet beam, is built of iron, and has a capacity of twenty-four large box cars. The average time made by a tug towing one barge across the bay in good weather is four and a half hours, and by towing two from five hours to five and a half hours. The total number of freight-cars transferred in the year 1894 was 36,772. This route lies straight across the Chesapeake Bay, and is exposed to the heavy Atlantic

[1] Minutes of Proceedings Inst. C.E., vol. cxviii. p. 263.

seas, but there are probably, on an average, not more than half-a-dozen days in the year when the barges are unable to cross.

A car-ferry service has recently been opened on Lake Erie between Conneant harbour and Port Dover, Ontario, a distance of 65 miles. One vessel has been in service since September, 1895, and it was expected that a second would be put on in October. These vessels are designed to carry twenty-six 30-ton cars or thirty smaller cars each, and have been built by the Craig Ship-Building Company of Toledo. They are 300 feet long, 52 feet wide, and 53 feet deep from the top of the pilot-house to the keel, and draw 12 feet when fully loaded. Each boat has four tracks, and is provided with compound engines of 2,000 HP.; each has twin screws in the stern, and a large club screw at the bow. They are fitted up with electric- and search-lights, steam capstans and steam steering-apparatus, and the builders guarantee a speed of 13 miles an hour in ordinary weather.

The Author also describes briefly several other car-ferries, of which he states that the system of the Lake Michigan Car-Ferry Transportation Company is the most ambitious. This ferry is between South Chicago and Peshtigo Harbour, a distance of 240 miles, and the service is made by specially built vessels carrying the trains of cars on their decks, but with no power for propelling, the only steam-power they have being for the purpose of working the steam-towing apparatus. The vessels are towed by powerful tug-boats. Each of the vessels can carry twenty-eight freight-cars; they are 316 feet long, 24 feet wide, and draw 7 feet. The vessels are towed by means of a steel hawser wound on a drum on the towed vessel, which drum is geared directly to a small engine, making an elastic connection; the strain of the hawser is always acting directly against the steam. The Author states that this arrangement is very speedy and convenient for altering the distance between the tug and vessel, and expedites the handling of the vessels in port. The voyage from port to port takes from twenty-eight hours to thirty hours.

Two illustrations accompany the Paper. J. A. T.

The Lausanne Tramways. By J. Prouteau.

(La Revue Technique, 1895, p. 444. 1 Fig.)

The proposal for constructing tramways at Lausanne dates from 1869–1872, when the lines of Lausanne-Ouchy and Lausanne-Echallens were built, and the honour belongs to Mr. Gossin, the engineer of the canton.

The proposed system was that of Mékarski, each carriage being provided with a separate compressed-air motor. In 1882 another engineer, Mr. Bergeron, proposed a cable line on the Hallidié (*sic*) system which is used in San Francisco, and to serve the environs

as well as the town of Lausanne. In 1888 Mr. Vautier was instructed to prepare a scheme based upon the Abt rack system, but it was found that the engines would be so heavy that electricity proved to be the only practicable form of energy. In the first scheme of Mr. Palaz, the engineer, it was proposed to use the water-power of the River Bret, but this proved unsatisfactory, and was given up in favour of a generating station at Pontaise where either oil-engines or generator gas-engines should be used.

Mr. Palaz obtained the necessary concession from the Federal Assembly on 21st December, 1894. The trolley system, with return by the rails, has been decided upon, owing to the local conditions. Accumulators will not be used owing to the steep gradients. Steam traction would have been impossible upon the Chailly and Pontaise sections, and the compressed-air systems of Messrs. Popp and Conte were considered to have been put to very little practical use as yet. It was proposed that water-power from the Jura or the Alps should be used as a source of energy, but it was finally decided to build a special station and use engines. The building is to consist of two parts; the one facing the Rue Saint Martin will be 56 feet square by 26 feet 3 inches high, and will contain the engines and dynamos, the other will be 41 feet by 38 feet, and will contain three gas-producers and accessories. There is also an accumulator-room.

Engines working with producer gas have been decided upon of the type built by Messrs. Crossley Bros., and using only 1·21 lb. of anthracite per HP.-hour in ordinary work.

At first only two producers will be put down, and two engines of 130 HP. each, and one of the engines will work about 18 to 20 hours per day. The battery of accumulators will have an output of about 200 HP.

The track is of metre gauge, and consists of Phénix rails weighing 64 lbs. per yard, carried on metal sleepers weighing 30 lbs. per yard. The feeders are partly underground and partly overhead.

Each car carries thirty passengers and is driven by two motors, each of 20 HP., driving the axles through a single train of gear. It is fitted with hand-brake, electric-brake, and a safety-brake acting by pressure on the rails.

The costs are as follows:—

	£.
Site and buildings	8,800
Generating station	10,800
Track and electric fittings	14,600
Rolling stock	9,800
Administration and unforeseen	6,000
	£50,000

The service will be at intervals of eight minutes or sixteen minutes according to the district served.

E. R. D.

The Continuous Rail in Street-Railway Practice.

By Richard McCulloch.

(Journal of the Association of Engineering Societies, New York, 1895, p. 175. 7 Figs.)

Tramcars are now to be seen 35 feet long weighing 24,000 lbs., and following each other at intervals of one minute at speeds of 20 miles per hour. The joints of the rails are the chief points of weakness. In 1892 the Johnson Company of Johnstown, Pa., began to experiment with a rail 6 inches deep, weighing 78 lbs. per yard, and continuous for a length of 1,160 feet. Careful readings of temperature were made three times each day and three times each night from March to September, the air temperature varied from 10° to 89°, and no movement of the rail could be detected either longitudinally or laterally.

The method adopted by the Johnson Company after this satisfactory result was electric welding; a machine for the purpose was built by the Thomson Welding Company, and in 1893 about 3 miles of track in Johnstown and about 8 miles in Boston were electrically welded. During the winter 1893–4 about 6 per cent. of these joints broke. Some defects in the process were remedied, and in the spring of 1894 6½ miles of track in St. Louis were welded, in Cleveland 5 miles, and in Brooklyn 32 miles. At first the rails were not butt-welded end to end, but were joined by a span welded to the web of the rail at about 4 inches from the ends. The breaks did not occur at the joint nor in the span, but in the rail where the span had been welded on, due, it was thought, to internal strains having been set up. A new form was devised and an actual butt-weld made and used at St. Louis.

The Author gives a description of the process, from which it appears that the continuous current at 500 volts is taken from the overhead wire and feeds a rotary transformer, which converts the direct current to alternating current. This transformer is an ordinary 4-pole 100-kilowatt dynamo by the General Electric Company, U.S.A. The periodicity is about 73 per second; the alternating current passes through a reaction coil with a movable iron core to the welding machine; the rail joint completes the secondary circuit. Great pressure is brought to bear upon the weld by means of a toggle joint.

The car weighs about 30 tons, and all the work is done in the rear of the car, so as to obviate the necessity for passing over the hot joints.

Four lugs are used at each joint and two welds are necessary, the bottom two being welded in one operation and the upper two in the next. During the welding operation, which lasts one or two minutes, the direct-current transformer takes from the line about 250 amperes at 500 volts. This is transformed down in the secondary of the welding machine to about 4 volts; the current

which passes through the lugs on the rails is consequently 20,000 amperes to about 30,000 amperes. The Author then describes in detail the whole of the operation. In St. Louis the machine completed from thirty to fifty joints per day of ten hours. Another and entirely different process is that known as cast-welding, exploited by the Falk Manufacturing Company of Milwaukee. This, to briefly describe it, consists of clasping the ends of the rails for about 8 inches on each side of the joint by means of a mould, and then pouring the mould full of molten iron. The iron solidifies on the rails around the joints and makes a partial union with it.

In order to compare the two methods, the St. Louis Railroad Company had about 3 miles of track in the southern part of the city connected by the cast-welded process in October and November, 1894. The results were so excellent that in relaying the old cable track it was decided to use the cast-welded joints. The apparatus for casting the joints consists of a cupola furnace mounted on a heavy truck; the cupola is 2 feet diameter, brick-lined, and the blast is furnished by a rotary blower actuated by a 5-HP. electric-motor receiving current from the trolley. Seventy-two joints have been poured at one melting.

The results obtained on the Baden Road in 1894 are, that out of 2,203 joints electrically welded 3·27 per cent. have broken, and half have been repaired by the cast-welding process.

In Cleveland during the summer of 1894, 3,400 joints were made electrically, two-thirds on 56-lb. rail, and the rest on a 90-lb. rail; out of these the total breakage last winter was six, or 0·18 per cent.

On the South Western Railway, on Chippewa Street, 744 joints were made by the cast-welding process, and during the winter only three, or 0·43 per cent., broke. In Chicago 11,903 joints were made for the City Railway, and 8,867 joints for the West Chicago Railway Company by the cast-welding process.

The Author gives a calculation of the stresses produced in long welded rails by expansion due to atmospheric changes, and draws attention to the extraordinary grip obtained on the rail by macadam. Electric welding is scientifically a beautiful process, and, if well carried out, the joint is stronger than the rail; it is, however, difficult to operate when the voltage fluctuates. The welding machine is very heavy, costly and cumbersome. Cast-welding is carried out with a light machine of no great cost. The cost of either process does not greatly exceed the old fish-plate method, and any form of welding obviates the necessity for bonding the joints of electric roads.

E. R. D.

Some Preventable Wastes of Heat in the Generation and Use of Steam. By W. Kent.

(Journal of the Franklin Institute, December, 1895, p. 406.)

The Author describes the chief causes of waste of heat under the following heads: Waste in the boiler furnace; in the boiler itself; in the chimney gases; in the steam-engine.

The chief source of waste in a boiler furnace is due to bad furnaces and improper methods of firing. At the Chicago Exhibition of 1893, thirteen boilers were tested with good anthracite, and gave an evaporative value of 10 lbs. to 12 lbs. water per lb. of coal, from and at 212° F. One of the chief reasons for deficient evaporation is that the carbon is burnt to CO, instead of to CO_2. With proper attention to the thickness of the coal on the grate and the draught, the waste may, in the Author's opinion, easily be controlled by the stoker. A dull red fire is always with anthracite an indication of imperfect combustion.

Another considerable waste is caused by allowing too much air to pass through the fire, thus cooling the boiler, and carrying off unconsumed gases, which are rapidly distilled at a comparatively low temperature. The dense pall of smoke over manufacturing towns is a proof of bad engineering, and shows that there is incomplete combustion and loss of heat. In the boiler itself the waste is generally due to insufficient heat-absorbing surfaces, the gases being sent to the chimney at much too high a temperature. A good rule given by the Author is to allow 3 lbs. of water evaporated per hour per square foot of heating surface, or even $4\frac{1}{2}$ lbs. per square foot, but more than this will result in waste of heat up the chimney.

Another difficulty is that the hot gases are often not guided uniformly over the whole extent of heating surface, but escape to the chimney without passing through all the rows of tubes. Some of the latter are thus rendered ineffective. Very much depends on the condition of the boiler plates; scale and soot are both bad conductors of heat, and hinder transmission. The first condition of steam-boiler economy is a high furnace-temperature, the second a low chimney-temperature. If the firing, draught, and thickness of coal are properly regulated, these conditions will be attained; if they are neglected, imperfect combustion, low furnace-temperature, smoke, and loss of heat up the chimney will be the result. Generally too much air passes through the grate, and the latter is often too small, and easily choked with clinker. The fire-doors are also open too frequently and too long.

As to the temperature of the chimney-gases, it is quite possible to reduce it to about 100° F. above the temperature of the steam, or say, 400° F. to 450° F. Taking the temperature of the furnace at about 2,400° F., and the gases at 400° F., the chimney-loss, even then, would be about 15 per cent. of the total heat generated.

Part of this loss is unavoidable, but much may be saved by the use of an economizer or feed-water heater. A further waste is due to radiation from the steam-pipes, which should be very carefully clothed.

Lastly, there is the waste of heat in the engine itself, chiefly attributable to cylinder-condensation. With the old low-speed, non-condensing, single-cylinder engines the consumption was about 45 lbs. water per I.HP. hour ; in the best modern triple-condensing engines it is about 12½ lbs. The heat-efficiency of the latter is about 18½ per cent. ; in other words, only 18½ per cent. of the total heat given to the engine is utilized. If the boiler efficiency be taken at 75 per cent., there results a total efficiency of engine and boiler combined of 14 per cent., or only one-seventh of the total heat generated. With existing knowledge it does not seem possible, in the best engines, to avoid the waste of even more than the other six-sevenths. In practice the preventable waste is often enormous, sometimes as much as three or four times more than the above. To determine and check great wastes of fuel, the gases of combustion should be frequently analysed, and their temperature taken.

B. D.

On Smokeless Combustion and Boiler-Firing. By W. Hempel.

(Stahl und Eisen, vol. xvi., 1896, p. 87.)

The statement, common in text-books, that carbon burns to carbonic acid when enough oxygen is provided, and to carbonic oxide when the supply is insufficient, was shown by the Author to be erroneous some years since. The character of the gaseous products depends largely upon the conditions of temperature and pressure, the quantity of oxygen present being only of importance when subsequent application of those products are in question. At a low temperature, carbonic acid, with merely traces of carbonic oxide, is formed, whether the supply of oxygen be much or little, while at higher temperatures carbonic oxide preponderates, with a very small amount of carbonic acid. Thus the gases from charcoal burning at a dull red heat in air contained 13 per cent. of CO_2 and 8 per cent. of oxygen ; but when the temperature was raised to a brilliant white heat by blowing in oxygen, CO_2 fell to 2 per cent., although considerably more oxygen was present in the second than in the first experiment. In another case, a gas-producer fed with coke and brought to a strong heat by a free supply of air was allowed to cool down slowly, and the composition of the gas was determined at regular intervals during the cooling, no excess of oxygen being present at any time. The results were :—

	Beginning						Ending
CO_2 .	4·4	7·2	11·0	14·8	16·5	18·9	19·8
CO .	23·8	20·6	15·8	7·1	1·7	1·0	0·0

The influence of pressure, however, is in the opposite direction to that of temperature or towards higher oxidation. Carbon in this respect behaves similarly to sulphur, which burns in the air to SO_2, but when the combustion is effected with oxygen in a closed vessel at 41 atmospheres pressure, the gas contains 65 per cent. of the sulphur as SO_3, and 35 per cent. as SO_2.

At the request of the Saxon Society of Engineers and Architects, Professor Lewicki and the Author have examined a number of steam-boiler furnaces selected as types among those that had been reported by inspectors either as smokeless, or as smoking badly, and have arrived at the conclusion that the most important condition to be fulfilled is proper stoking. Any, and all, mechanical appliances are insufficient to prevent smoke, if the air-supply is not exactly right, while the ordinary plain grate works admirably if it is intelligently handled. The generally-prevalent opinion that there is a great loss of fuel in smoke is incorrect, as even in a very smoky flame only traces of carbonic oxide and marsh gas were found. The principal condition for smokeless combustion is a high flame temperature. Smokeless firing may be effected with the ordinary grate if the fresh coal is uniformly spread over it in a thin layer; but a simpler method is to push the fire back to make room for the fresh coal in front. In this way the fuel becomes completely coked at the bridge, and the heat radiated is sufficient to start the distillation of the coal, and to burn the gases evolved without smoke.

A most important matter is the use of sufficiently deep fire-bars, which should be of uniform section throughout. These are useful as a means of heating the air before it enters the fire, and reciprocally the latter cools the bars and so tends to preserve them. It often happens that in providing a very large heating-surface in boilers the necessity of an air-tight external casing is overlooked. This is especially the case with water-tube boilers set in brickwork, and fitted with large cast-iron doors, the former being very permeable, while the latter warp under the heat, and cannot be kept tight. In such cases it is absolutely impossible to get a high proportion of carbonic acid in the gases, and if it does not exceed 8 or 9 per cent. the result, even with the most perfectly-arranged heating-surface, will always be bad. In this respect internally-fired boilers are far better, as, the fire being enclosed in an air-tight tube, the air-supply can be easily regulated so that there shall be no unnecessary excess, at any rate at the place of most active combustion. The fire-grate is also in the most advantageous position for giving a maximum transfer of heat by direct radiation. In such boilers it is easy to obtain 15 per cent. of carbonic acid in the chimney gases, or even 18 per cent. under the most favourable conditions.

The proper regulation of the air-supply cannot be too strongly insisted upon, and the composition of the gases should be regularly determined, either by analysis or the gas-balance. As the maximum heat-transfer takes place from the hot flame the degree

of combustion is of more importance than the sensible temperature in the chimney. Thus a boiler giving off gases with 15 per cent. of CO_2 at 300° C. is far more effective than one in which the proportion is reduced to 7 per cent., even though the chimney-temperature may be only 150°. H. B.

The Chemistry of the Prevention of Incrustation in Boilers.

By H. DE LA COUX.

(Le Génie Civil, January 11 and 18, 1896, p. 170 *et seq.*)

After remarking that the real practical solution of this problem —namely, the separation of the soluble impurities of feed-water— is still unsettled, the Author briefly considers the usual methods adopted to minimise the inconveniences caused by the deposit of these salts as scale in the boiler. He divides these methods into three classes—mechanical, chemical, and localising. The latter merely consist in localising the deposit to portions of the boiler where it can be more easily dealt with.

Among mechanical methods, the Author includes the use of inert substances, such as clay, powdered glass, zinc filings, and various vegetable solutions; also coatings of oil or similar substances on the inside of the boiler. These substances are intended to prevent the adhesion of the deposits to the inside of the boiler, but their employment is more or less unsatisfactory and attended with disadvantages.

The chemical methods consist in the addition to the water of various salts, or other substances, which, by combining with those dissolved in the water, are more easily dealt with, either on account of their decreased solubility or otherwise. The impurities most usually met with in solution are carbonates or sulphates of lime, and the Author considers the various chemical changes which take place on the addition to such water of the following substances:—

Silicate, carbonate and oxalate of sodium, alkaline tannates, glycerine, fatty and saccharine substances, including treacle (these all being introduced into the boiler, the object being to form a non-adhesive deposit); lime, magnesia, soda, potash, and chromates or aluminates (these being added in a separate tank in order to precipitate the impurities before the water is fed into the boiler).

The Author points out that with the organic substances above mentioned, the action is not sufficiently sure to be altogether satisfactory, but that with the mineral salts fairly good results can be obtained. A careful analysis of the water to be treated is, however, necessary, and the Paper concludes with an example of the method of determining the quantities of the various salts to be added to limy or selenitic water in order to precipitate these soluble salts. R. B. M.

Advantages of Increased Height of Boiler and Centre of Gravity in Locomotives.

(Le Génie Civil, November 23, 1895, p. 49.)

The writer first refers to the relative practice with respect to height of boiler and centre of gravity of locomotives in America, England and Continental Europe, the American engines being considerably higher than those in either England or the Continent. He then considers the effect of raising the centre of gravity of a locomotive, and shows how the stresses on the rail due to centrifugal force or to rocking can be in this way considerably reduced, while the running is correspondingly easier; and he draws a comparison between a locomotive with a high centre of gravity and a ship with small stability. This raising of the centre of gravity, however, can be carried to excess, as is the case if the stability of the locomotive at high speeds round curves is thereby endangered. The Author next discusses the effect of raising the boiler, thus enabling a boiler of greater power to be employed, and giving more space for the machinery, and he draws attention to the comparatively small effect of such raising on the centre of gravity of the engine, owing to the greater proportion of the weight being contained in the other portions of the locomotive. He considers that even in the case of the highest locomotives yet constructed the centre of gravity is still below that of ordinary loaded box-wagons, though he points out that in tank-engines it is probably higher than in ordinary locomotives.

He concludes:—(i) that within certain limits, which have not yet been reached even in America, raising the centre of gravity of locomotives is in every way advantageous, lessening the stresses on the permanent way, and on such portions of the engine itself as wheels, axles, axle-boxes and frames, while the motion is easier, and the tendency to leave the rails round curves is diminished; (ii) that raising the boiler appears to be the cheapest and most feasible method of obtaining an increase in the power of the locomotive; (iii) that as the boiler only forms about a quarter of the weight of the engine, raising the former by any given amount only raises the centre of gravity of the whole locomotive by about a fourth of that amount; and (iv) that the centre of gravity of the highest locomotives being still well below that of the heaviest loaded wagons actually in use the former can be safely raised without fear of endangering the stability.

The article is accompanied by a photographic view of a New York Central engine, and a fire-box-end view of the same; and also by two small diagram cuts, one giving front outline views of an American, an English, and an old French locomotive, and the other a side outline of the American engine, with a French express locomotive superimposed in hatched lines.

R. B. M.

Steel Transport-Boat with Naphtha Motor and Turbine-Screw Propellers. By W. Reitz.

(Schweizerische Bauzeitung, 1895, p. 99.)

The two steel boats, the "Wisla" and "Nareff," described in the present Paper, were constructed at Zurich for the Russian Government. Each boat was specified to accommodate twenty men fully equipped, to take fuel sufficient for thirty hours steaming at full pressure, to have a maximum draught of 1 foot 2½ inches, and to maintain a speed of 7½ miles per hour throughout a three-hours' trial in smooth water.

The total length of each boat is 45 feet 3 inches, and actual draught under 1 foot 2 inches. The engine, placed about one-fourth the length from the stern, is a naphtha motor, which takes about one-eighth the space, and is comprised within one-twelfth of the weight of an ordinary steam marine-engine and boiler of equal power. In two minutes from lighting up, the engine is ready to start.

Having regard to the broad beam and attenuated draught, an ordinary screw propeller would not have had sufficient water area; a new form was therefore adopted, of the turbine-screw type. This propeller works in a comparatively small diameter, and without lashing the water into foam, so that the boat glides through the green water with the minimum of disturbance. There are two parallel screw-shafts, working in cylindrical casing fixed below the stern framing, and fitted with three-bladed turbines, the blades being much longer than ordinary screws. The water is drawn in at the fore end of this cylinder. The waterway tapers from fore to aft, so that the water-jet is contracted at its outlet, where it attains its greatest velocity. Beyond the screw the water traverses an outside cylinder with nine blades, by which it is discharged parallel with the propeller axis, and screened on each side, so that the whole available propulsive force is concentrated in an effective manner.

P. W. B.

Trials of the Sea-going Torpedo-Boat "Forban." By G. Hart.

(Résumé de la Société de Ingénieurs civils de France, 18 October, 1895, p. 266.)

The "Forban" was built by Mr. Normand of Havre. Her displacement is 125 tons. She is propelled by twin screws turning in the same direction, and the total I.HP. developed is 3,650. Steam is supplied by two water-tube boilers. Feed-water heaters and filters are fitted. The trial consisted of two series of three runs on the measured mile at Cherbourg, separated by a straight run of one hour, and the speed during this hour was ascertained from the

data obtained on the measured-mile runs. The mean speed during the hour was 31·029 knots, and the coal consumed was 5,950 lbs., or at the rate of 1·61 lbs. per I.HP. per hour. The load carried on trial was 16 tons.

S. W. B.

The Problem of Torpedo Discharge.

Compiled from the Report of Lieut. F. F. Fletcher, U.S. Navy.

By Lieut. Albert Gleaves, U.S. Navy.

(Proceedings of the United States Naval Institute, 1895, p. 339)

The most potent factor in the successful run of a torpedo is the initial dive when discharged from an above-water tube, and this depends directly upon the angle at which the torpedo enters the water. This angle must be such that the torpedo, when submerged, is pointing in the line of fire and at such an inclination that it will neither rise to the surface nor make a greater dive than 20 feet without coming under the influence of its own controlling mechanism. As the conditions which affect the angle of entry are not the same in all ships, it is important to know how to vary each one so as to produce at all times a uniform submerged angle of entry, because it is their final angle that determines the depth of the dive. There are five elements that influence the angle of entry; these may work together to produce a satisfactory result, or they may be either partially or altogether opposed to each other. They are—1. Impulse pressure; 2. Initial velocity; 3. Height of tube; 4. Inclination of axis of tube; 5. Length of spoon.

As soon as a pressure of about 5 lbs. is developed in rear of the torpedo it begins to move, and quickly attains a velocity of about 32 feet per second. When the guide stud, which is placed immediately over the centre of gravity of the torpedo, leaves the T slot at the end of the spoon the centre of gravity begins to fall, while the tail is still supported some distance inside the tube. During the time the torpedo is travelling the distance necessary to free the tail its motion is that of a pendulum, and the centre of gravity swings through a small arc with a constantly accelerating rate due to gravity. The angular motion in the vertical plane thus imparted to the torpedo will continue at a uniform rate at the instant the tail begins to fall until the torpedo strikes the water. The value of this angular impulse depends directly upon the velocity of discharge, and a variation in the velocity gives a corresponding variation in the angle of entry for any given height of tube. Again the angle of entry depends upon the time through which the angular impulse has acted; and, therefore, varies with different heights of tube. Upon striking the water the torpedo has not only an angular motion around its centre of gravity, but

a lateral velocity due to the impulse pressure, and a vertical velocity due to gravity. The resultant direction of motion is, therefore, at an angle to the surface of the water depending upon the two velocities, and the direction of its axis is also at an angle to the surface depending upon velocity of discharge, height and depression of tube. The head of the torpedo first strikes the water, and is considerably retarded, while the after portion is free to fall through the air. The angular motion is not only checked but a reverse angular motion takes place, tending to bring the torpedo back to horizontal.

The charge of powder used in the experiments forming the subject of the report was about 4 ozs., 1 oz. being in sphero-hexagonal pellets lying in the bottom of the cartridge-case, and three ounces in square grains, such as are used in the 6-pounder R.F.G. The average maximum pressure in the tube was about 21 lbs. per square inch, and the velocity of discharge 30 foot-seconds. The maximum pressure is attained when the torpedo has moved about 4 inches, and is maintained for a distance of about 10 inches, after which it falls to zero. When the pressure disappears, the tail of the torpedo is still 4 feet 6 inches inside the tube. The variation of muzzle-velocity with pressure was found to be as follows:—

Pressure.	Velocity.
Lbs.	Foot-Seconds.
20	31·1
21	32·6
22	32·6
23	35·2

The initial dive is increased by the height of the tube above water, and by the angle of depression. With a height of tube of between 5 and 6 feet, the dive is about 9 feet, but from a tube three feet higher the dive is nearly doubled. A difference in the angle of depression of 6° has an equal effect upon the depth of dive as an increase of 4 feet in height above water. The following Table shows how much the entering angle or initial dive is influenced by a variation in the muzzle-velocity:—

Muzzle Velocity.	Angular Velocity per Second.	Height of Tube, 5 feet; Time of Fall, 0·56 second.	Height of Tube, 7 feet; Time of Fall, 0·66 second.	Height of Tube, 10 feet; Time of Fall, 0·79 second.
	°	° ′	° ′	°
26	31·50	17 38	20 48	24 48
30	25·83	14 30	17 5	20 35
34	21·07	11 48	13 54	16 40

In general it may be said that a variation of 1 foot in the velocity of discharge will cause a variation of about $\frac{3}{4}°$ in the angle of the torpedo entering the water.

Upon the length of spoon, more than upon any other condition, the angle of entry depends. The shorter the spoon the greater is the angular velocity and entering angle. The length of spoon in use in the American Service is 5 feet. For every inch this spoon is shortened it should make a difference of about 1° per second of fall.

Relation of Angle of Entry to Initial Dive.

Angle of Entry.	Average Dive.
°	Feet.
13–15	9
15–17	11¾
17–18	15
20–22	17⅓

The article is illustrated by photographs of torpedo flights and by diagrams showing curves of speed and depth of run.

S. W. B.

On the Hydraulic Press in Girder Manufacture.

By Julius Buch.

(Stahl und Eisen, 1895, p. 1143.)

The dimensions of joists and other heavy sections in mild steel, as now manufactured, are limited by the necessity of using a large number of mill grooves for the progressive reduction of the ingot, an intermediate heating being also often required between the cogging and finishing stages. The largest section that can be advantageously rolled at present is 550 millimetres (19½ inches) high, 200 millimetres broad, 9 millimetres in the web, weighing 169 kilograms per metre, and to produce this at a reasonable speed this involves the use of five to six stands of two-high, or four to five of three-high, rolls; the section also is made thicker and heavier than is required for structural purposes in order to keep the metal at the proper temperature for finishing. The Author proposes to produce larger sections by substituting for the cogging and roughing mills a combined vertical and hydraulic press, somewhat similar in arrangement to a universal mill, the vertical press and anvil having faces shaped to curves for forming the web, and the horizontal ones plane faces for smoothing the flanges. The length of the faces of both kinds is 1,250 millimetres in both cases, but those of the vertical press are tapered conically for half their length to allow the ingot to lengthen as the section diminishes. The press is fitted with live roller frames front and back lifting by hydraulic gear at the corners. An example is given of its application to the production of a joist 750 × 260 millimetres with 25 millimetres web, 25 metres (82 feet) long, weighing 290 kilograms per metre (195 lbs. per foot). This requires an ingot 2,350 millimetres long and 650 millimetres square, weighing about 7½ tons, which is

subjected at the proper heat to the vertical press acting on one-fourth of its length, with the horizontal rams open, which allows the metal to spread laterally about an inch beyond the width of the pressing face; the thickness in the middle being reduced from 650 millimetres to 305 millimetres. The curvature of the ends is then removed, and the breadth brought back to 715 millimetres by the flat faces of the horizontal presses, the other three-fourths of the ingot being similarly treated in their turn. The operation is then repeated, the thickness in the middle being brought down to 110 millimetres, and in the ends from 600 millimetres to 405 millimetres, but the side rams being kept close, the ends are flat. The reduction in the section of the ingot is 98,500 square millimetres at the first and 171,000 millimetres at the second pressing, the corresponding displacements in the length of 600 millimetres being 59,100,000 cubic millimetres and 102,600,000 cubic millimetres. From the press the bloom passes to a roughing mill with a single shaping groove, and then through the finishers which require at most seven grooves to give the required section. These should preferably be two-high reversing mills.

The data for computing the necessary pressure have been obtained from the results observed in pressing steel ingots into armour plates with a 10,000-ton forging press. In this case the ingot 2,500 millimetres long and 1,300 millimetres square was squeezed in four passages through the press to a slab 4,250 millimetres long, 400 millimetres thick, and 2,500 millimetres broad, the latter dimension being the original length of the ingot.

The computed pressures and displacement are as follows:—Cross section of ingot, 1,690,000 square millimetres, area of pressing face 2,050,000 square millimetres, breadth of pressing face 820 millimetres, length 2,500 millimetres, pressure 10,000,000 kilograms.

—	Length.	Thickness.	Breadth.	Compression.	Displacement.	Displacement per Kilogram of Pressure.
					Cubic Millimetres.	Cubic Millimetres.[1]
Ingot	1,300	1,300	2,500	..	..	..
First pressing . .	1,880	900	..	400	820,000,000	82·0
Second „ . .	2,700	630	..	260	533,000,000	53·3
Third „ . .	3,750	450	..	180	369,000,000	36·9
Fourth „ . .	4,250	400	..	50	102,000,000	10·2

Considering the condition in the two operations to be similar, we should require for the first shaping $\frac{59,100,000}{82} = 722,000$

[1] These figures correspond to $\frac{1}{2}$, $\frac{3}{10}$, $\frac{2}{10}$ and $\frac{1}{16}$ of a cubic inch displaced per ton of pressure.

kilograms, or in round numbers 750 tons, and for the second, when the metal is notably cooler than at first, $\frac{102,600,000}{53}$ = 1,936,000, or say 2,000 tons. Allowing a considerable margin, therefore, it is evident that in the work under consideration a forging press of 2,500 tons would perfectly well replace the cogging and roughing mills.

H. B.

Recent Applications of the Poetsch Process in France.

By F. Schmidt.

(Bulletin de la Société de l'Industrie Minérale, vol. ix., 1895, pp. 273–416.)

This is an extract from a general memoir on the use of freezing machinery for sinking through water-bearing strata, with notices of the principal mines where the Poetsch process has been successfully adopted. It was first used in the Franco-Belgian coal-fields at Houssu in Hainault in 1885, and was introduced into France in 1890, having since been applied in sinking through the tertiary and cretaceous strata covering the coal measures at Vendin-Lens (two pits of 82 metres and 84 metres), Dourges 47 metres, Courrières 45 metres, Vicq-Anzin[1] two pits 102 metres, and Flines lez Raches[2] (p. 394). The last of these is interesting, having been accomplished under conditions of greater difficulty than any of its predecessors. The thickness of permeable strata to be traversed is 70 metres, a bearing for tubing being found in blue marls (*dièves*) at 72 metres to 79 metres. The tertiary sands and clays are 25 metres thick and the chalk about 50 metres. A heavy sheet of water was encountered at the junction of these formations, giving a flow from a single bore-hole of 1,200 cubic metres, rising 2 metres above the surface, and another in the lower part of the chalk between 65 metres and 70 metres, also overflowing. In order to stop these feeders, two towers in brickwork were built round the orifice of the pit, an inner one of 6 metres, and an outer one of 11 metres diameter, rising 1·6 metre and 2·6 metres respectively above the surface-level; but these were insufficient to keep the water-level constant, owing to a lateral flow accompanied by subsidence which was set up in the overlying sandy strata, which was only checked by putting down a special bore-hole to trap the spring at a distance of 25 metres eastward from the pit. This was perfectly successful, giving a steady head of 1·6 metre of water in the towers, and allowing the freezing to be begun.

The freezing circuits contained in bore-holes 75 metres deep were twenty-two in number, one being placed in the centre of the pit, which is 4·2 metres in diameter, and the other twenty-one on

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 541.

[2] Flines lez Raches is about 5 miles north-east of Douai.

a ring of 6 metres diameter. The cold was produced by a Fixary ammonia compression-machine, driven by a 500 × 900-millimetre single-cylinder engine, making 80 revolutions per minute, and capable of producing 1 ton of ice (equal to 100,000 calories abstracted) per hour. The principal peculiarity of this machine, which was also used at Courrières and Dourges, is in the method adopted for making the stuffing-box of the compressor gas-tight by allowing a small quantity of liquefied ammonia to volatilize in an annular chamber surrounding the rod, which freezes the lubricant into a pasty impermeable mass, the portion liquefied by the friction of the piston-rod being continuously removed to the rectifier where the oil and ammonia separate, the latter going to the compressor. The refrigerating and other arrangements for the circulation of the chilled solution of calcium chloride are generally similar to those of the Linde machine previously described.[1]

The freezing machine was started on the 1st of September, 1894, and in thirty-eight days the ice-wall was completely closed around the tubes. The sinking began on the 25th of October and the relief bore-hole was finally stopped on the 5th of November. The ground was broken in the upper strata by picks and wedges, but lower down blasting with compressed powder was adopted. The central tube was put out of use and removed progressively as the sinking advanced. At 14·8 metres two seating-rings of oak, respectively 22 centimetres by 24 centimetres and 22 centimetres square, were fixed for the first line of tubbing, which was built up in segments of oak, 16 centimetres, to a height of 2·6 metres above the surface-level, with a backing of concrete, 16 centimetres, which is increased to 70 centimetres near the surface. A second seating, with curbs of 22 centimetres by 24 centimetres and 22 centimetres by 20 centimetres, was placed at 25·93 metres, and a third at 43·82 metres, the latter having three seating-rings of 22 centimetres by 28 centimetres, 22 centimetres by 24 centimetres, and 22 centimetres by 22 centimetres section, and tubbing rings of 18 centimetres with the same thickness of concrete behind. In April, 1895, the pit was 70 metres deep, and the building of the tubbing was completed on the 1st of May. The work was done by incandescent electric lamps served by a dynamo in the same house as the freezing machine.

The cost of sinking in the frozen ground is estimated at about 2,400 francs per metre, or £87 16*s.* per yard, an amount made up of the following items :—

	Francs.	£	*s.*	*d.*	
Freezing	1,550	56	14	0	
Sinking	150	5	10	0	
Tubbing	650	23	16	0	
Concreting and sundries	50	1	16	0	
	2,400	87	16	0	per yard.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 541.

Other applications of the Poetsch method have been made in a sinking lately commenced at Ligny-lez-Aire at the western end of the coal-field, where the thickness of permeable covering is about 89 metres, and in the repair of the cylinder-pits of the Fontinette canal lift. These pits, of 4 metres diameter, were sunk by compressed air and tubbed with cast-iron between 1883 and 1887, but became leaky by irregular subsidence of the ground in 1893, so that it has been decided to replace the iron lining by brickwork 80 centimetres thick, reducing the diameter from 4 metres to 3·7 metres, with a considerable increase in the bottom bearing of the press, which will be a cylindrical block of brickwork 5·307 metres in diameter and 2 metres high (1,564 cubic feet). The freezing process has been adopted in preference to compressed air in making these repairs, to avoid the chance of disturbing the ground and so damaging the surrounding buildings.

The right-hand press was first taken in hand, the boat-cradle having been fixed at its upper level by two supporting girders 40 metres deep, the piston was disconnected and preparations were made for freezing by twenty bore-holes on a circle of 6·307 metres diameter, or 99 centimetres apart, and one in the centre. These are about 2 metres deeper than the bottom of the new foundation, and are lined with tubes of 150 millimetres bore and 5 millimetres thick. The 125-millimetre freezing tubes are of steel, and the 33-millimetre brine supply-pipes inside of iron. The collecting rings are of 100 millimetres bore and 5,050 metres diameter on the admission and 5·7 metres on the return circuit.

The simplification of the process by doing away with the use of the cold fluid suggested by Mr. Gobert, who proposes to volatilize the liquefied ammonia in the freezing circuits, and Mr. Koch, who depends upon gaseous expansion alone, are examined by the Author, who considers that, in the absence of results obtained in actual practice, these are not likely to be as certain or efficacious as the original method.

The introductory part of the memoir contains descriptions of the Carré-Kropff, Fixary, Linde, Osenbruck and Lightfoot freezing machines, and of the combined method of freezing and fire-setting in frozen ground employed in winter for prospecting for gold in the alluvial deposits of the Siberian Rivers.

H. B.

New Shaft at the Von der Heydt Colliery. By Dr. Klose.

(Zeitschrift für das Berg- Hütten- und Salinen-Wesen in preussischen Staate, 1896, p. 10.)

At the Von der Heydt Colliery at Saarbrücken it has been found necessary to sink a new winding-shaft, the Kirschheck shaft No. 3, for lowering and raising a thousand men. The shaft is rectangular in section, its internal dimensions being 12 feet

3 inches by 8 feet 2 inches. In order to accelerate the work a rise was put up from the second deep level. This operation proceeded very slowly. It was begun on the 1st of October, 1890, and was suspended at the end of May, 1891, when the sinking was only 39 feet distant. The sinking was begun on the 20th of July, 1890, and was carried out, in shale, soft sandstone, and hard conglomerate, without difficulty. In July, 1891, the holing was effected at a depth of 750 feet. With 325 working days, the average distance sunk per day was 27·5 inches. The cost was as follows:—

	£	s.	d.
Wages and explosives, for sinking	2,172	7	6
,, ,, for rising	522	4	3
Materials	1,373	14	11
Other costs	774	5	7
Total	4,842	12	3

or £18 10*s.* per yard.

The original idea was to line the shaft with brickwork. The successful use of cement bricks at a neighbouring colliery,[1] however, led to the adoption of that method of lining. The bricks consist of a mixture of coarse gravel, washed Moselle sand, and Portland cement, slightly moistened and stamped in an iron mould. The hardening is effected in the open air with frequent moistening with water. The bricks are 39 inches high and $13\frac{3}{4}$ inches thick. The section of the wall was divided into eighteen equal parts, so that sixteen ordinary shaft-bricks and two specially-shaped corner-bricks were used. A depression at the top of each brick received a ridge at the base of the one above it. A brick of the dimensions mentioned weighed 1,102 lbs. and a corner-brick weighed 1,432 lbs. The cost of the cement lining was—

	£	s.	d.
Wages	2,378	5	9
Material	4,453	4	5
Total	6,831	10	2

or £20 15*s.* per yard.

The total cost of sinking and lining was £10,674 2*s.* From this the value of the recovered temporary timber which was utilized elsewhere, £681 12*s.*, may be deducted, leaving £9,992 10*s.*, or, roughly, £38 10*s.* per yard. The memoir concludes with details of the winding-engine and engine-house, the pit-head gear, and other accessories, and is illustrated by three plates of dimensioned drawings. B. H. B.

[1] Transactions of the Federated Institution of Mining Engineers, vol. iv., 1893, p. 343.

On Firing Boreholes by Water. By L. Jarolimek.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1895, p. 609.)

The method of firing dynamite charges without flame, described in this memoir, depends upon the use of a very sensitive detonator, which is ignited by the heat developed in the hydration of a block of caustic lime. The arrangement, which has been fully tested by the Official Committee on Fire-Damp at Mährisch-Ostrau, is described as follows:—The ordinary blasting-charge of dynamite being loaded into the borehole in the usual way, the shot is fired by a short dynamite primer, contained in a case closed by a so-called heating-cone, which takes the place of the fuse. The cone is a block of compressed lime, about 1 inch or $1\frac{1}{4}$ inch diameter, and $1\frac{1}{2}$ inch to $2\frac{1}{4}$ inches long, about $\frac{1}{2}$ inch in the length being tapered conically to a diameter of 0·8 inch at the outside end; while at the broad end there is a cylindrical cavity of about $\frac{1}{4}$ inch bore and $\frac{3}{4}$ inch deep, in which the firing primer is placed. This contains a very sensitive charge, igniting at 100° to 120° C., an ordinary fulminate cap, placed in its mouth and projecting centrally into the dynamite above, serving to detonate the latter, which is about 2 inches long, giving a total length for the primer of about $3\frac{1}{2}$ inches. The casing is made of soft cotton cloth or lamp-wick, which readily absorbs water in a wet borehole; and the water being taken up by the lime, heat is developed by hydration sufficiently rapid to fire the charge in a very short time. The first effect of the hydration is to swell the lime-plug, and cause it to close the borehole tightly, which, combined with the central method of ignition and the presence of water in the hole, very effectually prevent the issue of flame when the shot is fired. The time required for firing depends upon the absorbent power of the cotton casing and the surface of the lime-block exposed, and with a thin loose cover and the whole of the lime bare may be as little as twenty-seven seconds to thirty-eight seconds. When, however, a less porous material, such as a thick lamp-wick, is used, and the lime is partially cased, so that only a portion of the surface is exposed, the interval between loading and firing may be considerably increased up to a maximum of nearly three minutes. This is done by what is called tempering the cones, *i.e.*, enclosing them in tin- or lead-foil, so that the water can only be absorbed at the small outer end, at the greatest distance from the detonator, which therefore takes a longer time to be heated to firing-point. The proportion of the exposed surface varies from about one-third in the ordinary-tempered block to one-ninth in the high-tempered and one-thirteenth or one-fifteenth in the highest-tempered. With the slowest firing the variation in the time of the explosion of a group of five shots was about one minute, between 145 seconds and 203 seconds, or an average of 170 seconds. According to the report of the Commission, the method is likely to be of great

value in firing mines, as in no case was any propagation of flame observed, when it was tested in an atmosphere containing both gas and coal-dust, and it is considered to be safer, cheaper, and not more troublesome in use than electric firing.

H. B.

The Deepest Borehole in the World. By — KÖBRICH.

(Vereins Mittheilungen zur österreichische Zeitschrift für Berg- und Hüttenwesen, 1895, p. 108.)

At Paruschurtz, near Rybnik in Upper Silesia, an exploring bore-hole, commenced in January, 1892, had on the 17th May, 1893, reached a depth of 2,003·34 metres (6,572·71 feet). The boring commenced with an initial diameter of 320 millimetres, went on regularly until the 19th November, 1892, when the rods in drawing broke near the surface, and a length of 566 metres fell to the bottom of the hole, then 1,319 metres deep, and was not recovered for some time. On the 17th May, 1893, when the maximum depth had been reached, the work was stopped in order to make temperature observations, and was not resumed till the 23rd August; but on the evening of the same day, before any further progress had been made, the rods broke again about 500 metres down, and as all attempts to lift the broken part failed, the work was abandoned after removing everything that could be saved; but in the end two diamond boring heads, 40 metres of core tube, and 1,343 metres of Mannesmann tubes were lost. The temperatures were taken at sixty-four stations, each having six thermometers, 384 observations in all having been obtained. The results show an increase of 57° C. (from 12° at the surface to 69° at the bottom); but the increment in depth differs from that obtained in other deep borings, being only 34·1 metres per 1° C. (62·1 feet per 1° F.), while at Schladebach it was 35 metres and at Sennewitz 36 metres per degree. This difference is, however, to be attributed to the disturbance caused by chemical change going on in the coal measures, not less than eighty coal seams, with a total thickness of 89 metres, having been bored through. The total weight of the rods in use at the end was 13·9 tons. The average depth bored on each of the 399 working days was 5·01 metres. The total cost was £3,761 or 37*s.* 6*d.* per metre, while the Schladebach boring of 1,748 metres cost £6 1*s.* per metre.

During the past thirteen years 400 bore-holes have been made by the Prussian Government for exploring purposes, with a total length of about 80 miles at a cost of about £650,000.

H. B.

Carbonic Acid Wells.

(Organ des Verein der Bohrtechniker, September and October, 1895.)

At two places in Germany, Sondra and Salzungen, large quantities of carbonic acid gas have been tapped by bore-holes sunk for prospecting purposes. At Sondra, on reaching a depth of 627 feet (191 metres) the 7-inch diamond drill was driven upwards with great force, followed by gas and water under such pressure that work was temporarily suspended. After some delay work was continued until, at a depth of 646 feet (197 metres), gas was again tapped at a pressure of more than 30 atmospheres. The volume of carbonic acid issuing from the bore-hole was so great that it was found impossible for any workmen to remain in the neighbourhood, and the shutting down of the well was attended with the greatest difficulty. Finally, arrangements were made for conducting the stream of gas to a distance, and after much trouble from fragments of rock and mineral water, which issued from the bore-hole at intervals, the tube was finally plugged.

At Salzungen the carbonic acid was tapped at a depth of 1,142 feet (348 metres), 262 feet (80 metres) of which were in very hard rocksalt. The tube lining the bore-hole was 4 inches (102 millimetres) in diameter, and was capable of resisting a pressure of 20 atmospheres; but as the gas, when tapped, exerted a pressure of 32 atmospheres, leakage took place at the joints of the lining tube. It became, therefore, necessary to shut off the gas from the outer tube, and to insert a new tube of greater strength inside the old one, so that the gas might be obtained at its full pressure. This was accomplished by the following means:— A perforated copper tube, of a size to fit the bore-hole, and 33 feet (10 metres) long, was fitted internally with an india-rubber collar into which another tube, slightly conical in section, could be pushed. The upper part of this internal tube was fitted with a bronze ring, the top of which was conical, and fitted the lower end of the new tube. The whole apparatus was lowered to the bottom of the well by means of the boring rods, which were then unscrewed and withdrawn. The new tube was then lowered into place, and its weight forced down the conical internal tube and caused the india-rubber collar to make a perfectly gas-tight joint. Illustrations of the apparatus used for shutting off the gas are given. The pressure of the carbonic acid gas rose at once from 20 atmospheres to 32 atmospheres, and as carbonic acid can be liquefied at 32° F. at a pressure of 36 atmospheres, but little additional pressure is required to bring it into the liquid form suitable for industrial use.

W. F. R.

Mine Surveying in the Upper Harz.[1] By O. Brathuhn.

(Das Berg- und Hüttenwesen des Oberharzes, Stuttgart, 1895, p. 232.)

During the past twelve years the plans of the Upper Harz mines have been thoroughly revised. All the measurements have been referred to one system of co-ordinates and to a common datum line. As origin for the system of co-ordinates the centre of the stone pillar in the Clausthal magnetic observatory was selected, and, as abscissæ axis, a line whose azimuth makes an angle of 30° with the meridian of the origin. The consequence is, that the abscissæ axis is at right angles to the strike of most of the veins worked. The datum line was taken as 600 metres above sea-level, and, consequently, all the workings are below it, and only negative heights have to be dealt with. In connection with the triangulation of the State Survey, a network of small triangles was laid over the whole region. All the triangulation points are carefully marked with stones, and form an excellent basis for all future surveys. The number of stations thus marked amounts to 200. For the underground surveys, the theodolite was used exclusively; and the method of working with fixed points was adopted, as local conditions render this most suitable. At each level a large number of angle-points remain marked in the hard rock, and these may be used for connecting up subsequent surveys. Orientation was effected by means of the magnetic needle. No other method could be used, inasmuch as the connection between the surface and underground surveys had usually to be carried out by means of one inclined shaft. The magnetic theodolite was used, in which the magnetic needle is suspended by a cocoon fibre, and provided with a collimation arrangement. For the observation of the variation, two declinometers, a recording and a Gauss reading declinometer, were provided. The determinations of heights were effected in the levels, which are usually horizontal, by geometrical levelling, in the inclined shafts by means of steel measuring-rods, the parts of which can be screwed together as required, and in the perpendicular shafts by means of a suspended plumb-line. There was rarely need to have recourse to trigonometric levelling.

The special mine plans are drawn to a scale 1 to 500 on sheets measuring 50 centimetres by 70 centimetres (19·7 inches by 27·5 inches). A separate plan is prepared for each level, and the workings are shown by means of dotted lines on the plan of the next level. The number of sheets amounts to 270. Besides these, general plans to the scale of 1 to 2,000 are contemplated. The elaborate system of water-supply for the Upper Harz mines is shown on a separate plan and section drawn to the scale of 1 to 12,500. A relief plan showing the district affected by the water-supply has also been prepared on a scale of 1 to 12,500.

B. H. B.

[1] The original is in the Library of the Inst. C.E.

Inflammable Gas in Non-Fiery Mines.

(Annales des Mines, vol. viii., 1895, p. 1.)

Outbursts of gas, which in some cases have given rise to explosions, having recently been met with in underground clay quarries, in non-fiery collieries, and in metal mines, it has been thought desirable to call attention to these outbursts and to the conditions under which they are produced. A series of six memoirs dealing with the subject have consequently been published under the authorization of the French Minister of Public Works.

In the first of these, Mr. Oppermann describes the occurrence of inflammable gas in the Bollène fireclay quarries. Sudden outbursts have been met with for several years past. The gas is stored in cavities where it occurs under pressure, and its disengagement has led to several serious accidents, particulars of which are given by the Author. In view of the fact that these outbursts of gas are met with only on reopening or on approaching old workings, it may be concluded that the gas has been derived from the decomposition of timber left in the workings.

Mr. Humbert describes some outbursts of inflammable gas that have occurred in the underground clay quarries at Vanves and Malakoff, Seine. An accident closely resembling a fire-damp explosion that occurred on the 10th September, 1874, at the Malakoff quarry at the gates of Paris, called attention to the gaseous emissions met with in clay quarries. The gases are stored under pressure, and their formation is attributed to the decomposition of old abandoned timber in the presence of water and air. Attempts have been made to explain their formation by the decomposition of lignites intercalated in the clay. The proportion of lignite is, however, too slight to give rise to the formation of an appreciable quantity of gas. Special regulations have been laid down for working in clay quarries liable to the occurrence of gas.

Mr. Roberti-Lintermans records a number of accidents caused by gas-explosions in the underground quarries of plastic clay in Belgium. He attributes the production of the gases to the decomposition of timber abandoned in a moist place or in a place where air is imprisoned and heated by the subsidence of plastic ground.

Mr. Léon discusses the outburst of gas that occurred at the Peyrotte pit of the Carmaux Colliery on the 4th February, 1858, and Mr. Leproux discusses another at the Marseille pit of the Montrambert Colliery, Loire, which occurred on the 21st July, 1894. In both of these places no fire-damp had previously been met with, and in both cases the formation of the gases is attributed to the decomposition of timber and of organic matter abandoned in moist places. The gases appear to have been composed of marsh gas.

Mr. Lodin records a series of observations on the occurrence of

gas in salt mines and in metal mines. He cites the instances collected by Mr. Bennett H. Brough[1] and by Professor C. Le Neve Foster,[2] and gives the results of a special study of the Pontpéan mine, where galena is worked with blende and pyrites. A number of accidents have been caused there by gas-explosions. The formation of the gases may again be attributed in some cases to the decomposition of timber, but in other cases this explanation is insufficient. It must be admitted that the liberation of inflammable gas is caused by the metalliferous contents themselves being impregnated with hydro-carbons at an epoch probably contemporaneous with their formation. Organic matter might have entered into the composition of the mineral matter filling the vein, and have led to the production of the gaseous hydrocarbons whose presence has frequently been proved in the contents of mineral veins.

B. H. B.

A Cage-drop with Hydraulic Balance.

(Comptes Rendus de la Société de l'Industrie Minérale, 1895, p. 272.)

At the north pit of the Saint Eloy Coal Mines near Saint Etienne, the material for filling the space left by the removal of the coal is lowered in cages to a depth of 164 metres at an average speed of 4 metres per second (forty-one seconds for 538 feet, or nearly nine miles per hour). Owing to the variable character of the load, from 1·2 to 2·5 tons, and the absence of any counterpoise, as the return cage comes up empty, the use of friction-brakes for regulating the speed would necessitate a considerable expense in the renewal of the brake-blocks, and a method of hydraulic balancing has therefore been adopted, in which the power developed by the load is employed in driving a mass of water backwards and forwards in a closed circuit at a speed which can be varied by throttling the area of the connecting channel. The arrangement, which is very similar in appearance to a small horizontal direct-acting, winding or hauling engine, has a cylindrical winding-drum 2·8 metres in diameter, 34 millimetres for the cage ropes, which is coupled by cranks and connecting-rods to the pistons of two horizontal cylinders filled with water, having a free communication from one side of the piston to the other through a connecting-pipe of large bore; which can, however, be diminished or entirely closed by a cock turned by a screw and worm-wheel gearing under the control of the brakesmen, five turns of the hand-wheel being required to completely open or shut the passage. The cylinders are 310 millimetres diameter and the stroke of the piston 1 metre, and as the drum makes $18\frac{2}{3}$ revolutions during the drop, the water in the cylinder is displaced nearly thirty-seven times in forty-one

[1] Trans. North of England Inst. Mining Eng., 1889, vol. xxxviii. p. 59.
[2] "A Text-Book of Ore and Stone Mining," London, 1894, p. 476.

seconds, and, becoming considerably heated by the friction, through the throttled passage, requires to be frequently renewed. This is done by a pair of feed-pipes at the bottom of the cylinder served by a supply under pressure, the heated water being discharged through waste cocks at the top. The loads dropped are of three different kinds, and the work developed under the different conditions, computed from diagrams taken on the cylinder, is as follows:—

		HP.
I. Two empty tubs . . .	resistance required . .	54
II. One full, one empty tub .	at normal speed . . .	75
	at the moment of stopping	105
III. Two full tubs		133

The maximum pressure corresponding to the last or full load on the machine is $7\frac{1}{2}$ atmospheres, and in order that this may not be greatly exceeded, a valve is placed at each end of the cylinder communicating by a separate pipe with the other end. These valves are loaded by springs to 10 atmospheres, so that in the event of the pressure becoming higher through a too sudden closing of the main passage, the valve at the end under pressure opens, allowing the water to flow back by the relief-pipe. As an additional precaution, the rims of the drum are fitted with hand-brakes, which under ordinary conditions are lifted, but can be applied by a falling weight released by a treadle at the brakesman's feet in the event of any mishap to the hydraulic gear. The machine has been at work for about a year and has been found to be easy to handle and costs very little for maintenance. The pit being at a distance from any of the colliery workshops it has not been found possible to employ the work developed in compressing air or lifting water so as to be able to utilize it as a source of power.

H. B.

The Francou Coal-washing Machine.

(Revue Universelle des Mines, 1895, p. 167.)

This is a new form of hydraulic jigging machine in which the jigging piston, instead of being moved through an eccentric or other mechanism from a rotating shaft, is attached to a steam piston in the manner of a single-acting steam-hammer, so that the length of stroke, instead of being practically invariable, may be altered within wide limits. As represented in the accompanying plate, the jigging hutch is a rectangular iron box 2 metres deep, with a sieve-plate measuring 1·1 metre by 1 metre at the top, the front wall below the sieve being inclined backward, giving a waste collecting box of triangular section with an acute point downwards. The pump cylinder with its steam motor stands upon a framing behind the washer, and is connected with it by an elbow pipe through the back wall of the latter. When at the

bottom of its stroke the pump-piston is about 2 feet above the level of the sieve, and the water for washing is drawn in through a special suction-valve at each stroke, so that there may not be any back motion through the bed of washed material. The washing piston of 50 centimetres diameter is attached to the same rod as the steam piston of 22 centimetres, which is lifted by the admission of steam below it and falls by gravitation. Air is admitted to the cylinder above the steam piston by an adjustable aperture near the top, which is covered near the top of the stroke, the small quantity of air enclosed forming by its compression an elastic cushion. The change of stroke is effected by tappets on the rod joining the two pistons, which act upon levers attached to the slide-valve, and shift it alternately from the admission to the exhaust portions, the length of stroke being determined by their distance apart. The sieve-plate is of brass, with perforations 1½ millimetre in diameter, and is laid with a slight backward slope; the washed shale being delivered into a side pocket provided with a bucket elevator, while the fine stuff falls to the bottom of the pointed hutch, and flows out continuously through a small delivery pipe without being allowed to accumulate. The washed coal is delivered through a spout in the front edge of the hutch in the usual way. The chief difference in the working from that of ordinary coal-washers is in the much higher lift given to the column of water on the sieve, which for dust sizes up to 5 millimetres is 60 millimetres, and for 2-inch nuts may be as much as 100 millimetres; the length of stroke in the steam cylinder being about five times as much. The larger lumps of shale accumulate on the sieve, forming a bed of considerable thickness, whose action is similar to that of the felspar lumps in the Lührig washer, so that only the finest particles of the waste pass through. An advantage claimed for this arrangement over the method of driving the piston at a constant speed, is that the time of fall is governed by the resistance of the bed to the passage of the water; so that, if a portion of the plate is blocked, the speed is checked automatically, while in the former case the whole volume of water is driven through the reduced area with increased rapidity, with the result of completely disarranging the separation.

The quantity of coal that can be washed per hour with this machine varies according to the grain of the material. With dust up to 5·8 millimetres, or even 10 millimetres, it may be up to 4 tons per hour; with 10 to 30 millimetre sizes 5 tons to 6 tons; and, with cylinders of sufficient size, 30 millimetre to 50 millimetre nuts may be treated at the rate of 8 tons per hour.

The machines have been adopted at Courcelle, where there are three at work. The Amercœur Briquette Works have seven, treating all sizes up to 2 inches. Messrs. Haymin have two at Marchieune and five at their briquette works at Somain in France, and others at Grand Boullon near Dour, and the Viviers Reunis at Gilly bring the total number in use up to twenty-two.

H. B.

Close-sizing before Jigging. By Robert H. Richards.

(Transactions of the American Institute of Mining Engineers, 1894, p. 375.)

The laws that are claimed to control jigging are those relating to equal-sized particles, interstitial currents, acceleration and suction.

Of these the first is generally considered most important, but it does not cover all the phenomena, and an investigation was undertaken by the Author to determine to what extent each of these laws bears on the results.

The experiments were wholly conducted with grains of small size, 0·1 inch in diameter and less, the minerals employed in the investigation and their specific gravities being:—

Mineral.	Specific Gravity.
Anthracite	1·473
Quartz	2·640
Epidote	3·380
Blende	4·046
Pyrrhotite	4·508
Magnetite	4·987
Chalcocite	5·334
Arsenopyrite	5·627
Tin stone	6·261
Antimony (artificial)	6·706
Wolframite	6·937
Galena (cubic)	7·586
Copper (Lake Superior)	8·479

The sizing in all cases was performed with a nest of sixteen sieves, the sizes of the mesh being carefully taken.

The first set of experiments were on equal settling particles in still water in a tube 9 feet in length. Fall velocities were obtained by allowing about 50 grains of each size to fall a distance of 8 feet in the tube, and the time of passage of the fastest grain was taken, and the time for the slowest grains after 90 per cent. of the grains had fallen. The results thus obtained are given numerically, and are also plotted and are compared with parabolic curves calculated from Rittinger's formula. Upon inspecting the diagrams three facts are noticed:

1. The lines of fastest grains and of slowest grains depart very considerably from the parabola, particularly the smaller sizes.

2. The space between the two lines of fastest grains and slowest grains is a wide zone or belt.

3. The width of the zone may vary greatly, depending upon the shape of the particles—for example, the copper zone is much wider than that of the galena.

With regard to the first point, Rittinger makes note of the fact that his formulas fail for finer sizes. These curves, therefore, place on record the degree to which they have failed with the minerals here tested, and show that the velocity of any mineral which tends to break into flat scales, or elongated grains (for

instance, copper or chalcocite), is so modified as to change its class entirely. Thus the curves for fastest grains of galena and copper are almost identical, although their specific gravities are widely different.

Each mineral has, therefore, its own "personal equation," and minerals cannot be classed by specific gravity alone. Hence no formula can be founded on specific gravity and sieve-size only. It must be modified by the coefficient of each mineral for practical use. The second point, also, was recognized by Rittinger, as is shown in his formulas for fastest grains and slowest grains. But the deduction which followed from adopting a mean value for these grains is not clear to the Author, who shows that as the fastest grain of quartz falls about 8·5 inches in one second, while the slowest grain of blende settles only 5 inches in one second, the product would be unjiggable according to the law of equal settling particles, and that, therefore, under no circumstances is the law of equal-settling particles the whole law of jigging.

The second set of experiments related to the effect of interstitial currents, to which Professor Munroe attributed the fact that a jig will separate much finer grains of galena and quartz than would be the case if the law of equal-settling particles was the only law of jigging.

In each case a mixture of quartz and ore of the minerals above specified was treated in a vertical tube with an upward current of water flowing at a rate sufficient to keep the particles in gently moving suspension. The speed of current was then slackened slowly, and the material as it settled was collected in batches, dried, and passed through the nest of sieves. The group of particles resting upon like sieves were then arranged in rows and photographed, which gives a most effective graphical record of the results obtained. Reproductions of the twelve photographs of the mineral pairs treated are given in the Paper. From the weights and sizes thus obtained the interstitial factors (or multiplying factors for obtaining the ratio of the diameter of the particle of quartz, which in the pointed tube will be in equilibrium with any mineral) are calculated. It is shown that interstitial currents have a real existence, and advance the ratio from the equal settling particles of the free-falling test, which for galena and quartz is given by Rittinger as 1 : 4, and which has been found in this investigation for 10 to 12 mesh quartz as 1 to 3·75.

A similar apparatus with the water-supply periodically interrupted was used to determine the effect of acceleration. Although logically some effect was expected, it was found that nothing whatever was gained by adding acceleration to interstitial currents.

The effect of suction was tested by the aid of a small jig with a movable sieve. The sieve was placed 1 inch from the bottom of a glass tube, 5 inches long and $1\frac{1}{4}$ inch bore, to which an adjustable vertical reciprocating motion was given. By arranging this tube so that its top is above, partly above and partly below,

or entirely below the level of the water during the stroke, much, little, or no suction was obtained with full pulsion. The tests were made with quartz and different sizes of galena and blende, different sizes of quartz, and with mixed sizes of different minerals in admixture of quartz.

Although the work was done on a small scale, which may have exaggerated some of the jigging results, the Author concludes that the effect of pulsion depends upon the laws of equal-settling particles, interstitial currents and perhaps acceleration. It saves larger grains of heavier material, or grains which settle faster and farther than the waste. The effect of suction depends on the interstitial factor of the minerals to be separated, and is efficient and rapid when the factor is over 3·70, but is much hampered and hindered if the factor is below that number, although it may be aided by a long stroke. Its chief function is to save small particles. For jigging mixed sizes, pulsion with full suction should be used, and for jigging closely sized products pulsion with a minimum suction. The degree of sizing needed as preparation for jigging to obtain the most perfect work depends solely on the interstitial factor. If the factor is above 3·70 sizing is simply a matter of convenience. Fine sluices should be removed and larger sizes may be treated separately. If the factor is below 3·70 close sizing must be adopted in order to effect the most perfect separation, and the closer the sizes are to each other the more rapid and perfect will the jigging be.

R. E. C.

On the Influence of Cold on the Strength of Iron and Steel.

By M. Rudeloff.

(Stahl und Eisen, 1896, p. 15.)

At the request of the Wilhelmshafen Navy Yard a series of experiments upon the behaviour of different kinds of iron and steel when cooled to very low temperatures have been carried out by the Author at the Charlottenburg Testing Institute. The samples included Siemens open hearth, basic Bessemer, spring and crucible cast steel and rivet-hammered and rolled wrought-iron, both in round and angle-bars, which were subjected to tensile compression and bending tests at the ordinary living-room temperature (60° F. to 65° F.), at the cold produced by a freezing mixture of ice and salt (– 4° F.), and at that due to the evaporation of solid carbonic acid (– 112° F.).

The tensile test-pieces, made circular from round and rectangular from angle-bars, and as nearly as possible of the same volume, 100 millimetres long and 80 square millimetres cross section, were tested under continuously increasing loads uniformly applied in a 50-ton Pohlmeyer machine, fitted with a recording

indicator. The average values deduced from the observations are contained in the following Table:—

Material.	Observed Values.					Proportional Values.				
	Temperature.	Tons per Square Inch.		Elongation per Cent.		$\frac{A}{B}$	Tensile Strains.		Elongations.	
	Deg.	A	B	C	D	E	F	G	H	J
I. Rivet iron, round bar, 1 inch . .	64	18·22	25·20	30·2	27·7	0·72	100·0	100·0	100·0	100·0
	−4	18·54	26·47	29·0	26·2	0·70	101·7	105·0	96·0	94·6
	−112	19·30	27·75	26·6	23·8	0·70	105·9	107·5	88·1	85·9
II. Siemens OH steel, angle 4×4×0·56 in.	64	15·23	25·65	39·5	32·8	0·59	100·0	100·0	100·0	100·0
	−4	15·68	27·68	38·0	33·3	0·57	102·9	107·9	96·2	98·5
	−112	18·85	28·70	..	[23·4]	0·66	123·8	111·9	..	[70·3]
III. Basic Bessemer, angle 4×4×0·56 in.	68	17·82	27·55	35·3	30·2	0·66	100·0	100·0	100·0	100·0
	−4	19·30	28·89	33·8	29·5	0·67	105·9	104·8	95·8	97·7
	−112	20·32	29·34	[31·9]	[26·2]	0·69	111·5	106·5	[90·4]	[86·8]
IV. Malleable iron, angle 4×2·6×0·36 in.	64	19·62	25·53	[28·8]	21·3	0·77	100·0	100·0	100·0	100·0
	−4	20·06	26·41	23·5	21·7	0·76	102·3	103·5	98·7	101·9
	−112	20·26	27·43	..	20·2	0·74	103·2	107·5	..	94·8
V. Spring steel, round bar, 1 inch . .	64	24·58	49·02	17·7	16·0	0·50	100·0	100·0	100·0	100·0
	−4	25·53	53·47	15·7	14·0	0·48	103·9	109·1	88·7	87·5
	−112	28·19	53·60	12·8	10·9	0·53	114·7	109·3	[72·3]	68·1
VI. Crucible cast steel, round bar, 1 inch . .	64	28 85	50·33	20·1	17·1	0·58	100·0	100·0	100·0	100·0
	−4	29·02	51·89	20·0	16·8	0·56	100·2	102·9	99·5	98·2
	−112	30·93	53·39	17·6	13·9	0·58	106·8	106·1	87·6	81·3
VII. Malleable iron, hammered round bar, 1 inch .	64	17·33	23·55	26·3	21·3	0·74	100·0	100·0	100·0	100·0
	−4	17·52	24·06	26·1	21·9	0·73	101·7	102·2	99·2	102·8
	−112	20·38	25·33	[27·8]	23·3	0·80	117·6	108·6	[105·7]	109·1

A. Elastic limit, tons per square inch.
B. Breaking strain „ „ „
C. Elongation per cent. at 1·2 inch from fracture.
D. „ „ on 3·6 inches.
E. Ratio A : B.
F. „ of elastic limits at different temperatures.
G. „ tensile strength „ „
H. „ elongations in column C „
J. „ „ „ D „

The general conclusions from these results are:—

1. Both elastic and ultimate limits are raised by cold.

2. For equal decrements of temperature, the change in the elastic limit is small down to − 4° but becomes more apparent below that point. With the breaking strain the reverse is the case, it being proportionately more affected by the cooling at the higher than the lower temperatures.

3. The elongation at fracture diminishes with the fall in temperature except in the case of hammered iron. The change is partly proportional to the loss of heat, but becomes more decided at the lowest temperature.

The change in mechanical properties by cooling is most marked in Siemens steel, and least in malleable iron, the alterations between the highest and lowest temperatures being in—

—	Elastic Limit.	Tensile Strength.	Elongation.
	Per cent.	Per cent.	Per cent.
Siemens steel . . .	23·8 increase	11·9 increase	30·0 decrease
Spring steel . . .	14·7 ,,	9·3 ,,	32·0 ,,
Hammered iron . .	17·6 ,,	8·6 ,,	9·4 increase
Basic Bessemer . .	11·5 ,,	6·5 ,,	13·2 decrease
Crucible steel . . .	6·8 ,,	6·1 ,,	18·7 ,,
Rivet iron	5·9 ,,	7·5 ,,	14·1 ,,
Angle iron	3·2 ,,	7·5 ,,	5·2 ,,

The tendency of the metal to flow when strained to the elastic limit is notably increased at low temperatures. A measure of this property is afforded by the length of the horizontal part of the curve in the strain diagram; and this was, in all cases, increased at the lowest temperature (up to four or five times that at 64°), and was even measurable with hard steels which do not show it under ordinary conditions. This confirms the result previously announced by Charpy that this property in all cases disappears by heating.

The compression tests were made with cylinders of equal heights and diameters, varying with the size of the bars from 8 millimetres to 20 millimetres (0·32 inch to 0·8 inch), which were subjected to ten blows from a falling weight so chosen that the striking energy for material of less than 50 kilograms (37 tons) tensile strength was 5 metre-kilograms per cubic centimetre, and for the stronger steels, Nos. V and VI, 20 metre-kilograms (corresponding to about 5 cwt. and 20 cwt. per cubic inch respectively).

A compilation of the results obtained is contained in the Table on the following page, which gives in columns A, B, C and D the compression produced by the striking energy of 10 kilogram-metres, 20 kilogram-metres, 30 kilogram-metres and 40 kilogram-metres per cubic centimetre, and in E a comparison of the average shortening at the lower temperatures expressed in percentage of that at 64°. The index numbers are the same as those in the former Table.

The amount of compression by impact, therefore, diminishes with the fall in temperature in the same manner as the elongation under tension; but the two changes are not exactly parallel. The loss of malleability is about 8 per cent. at 4° F. and 23 per cent. at 112° F. The change is least in hammered iron and most in rivet iron.

The bending tests showed that the flexibility is but slightly changed at 4° F. in any of the samples or in the soft rivet- and

Material.	Temperature.	A	B	C	D	E
		10	20	30	40	—
	Degrees.					
I.	64	13·2	21·5	28·1	33·2	100
	− 4	12·4	20·4	26·2	31·0	94
	−112	9·5	16·6	22·0	27·0	77
II.	64	12·8	21·5	28·3	33·3	100
	− 4	12·8	21·5	27·0	32·0	98
	−112	10·0	17·0	22·5	26·7	79
III.	64	13·5	21·4	27·5	32·4	100
	− 4	12·0	20·0	25·8	30·7	93
	−112	10·5	17·9	23·1	27·8	83
IV.	64	15·3	24·2	32·3	..	100
	− 4	13·0	21·4	27·5	..	[86]
	−112	12·2	21·0	27·6	..	[84]
V.	64	7·8	14·7	20·2	25·0	100
	− 4	7·0	13·5	18·8	23·5	92
	−112	6·1	12·0	17·2	22·0	83
VI.	64	8·3	15·5	21·5	26·5	100
	− 4	8·3	15·5	21·0	26·0	99
	−112	6·0	12·0	17·8	23·3	80
VII.	64	13·8	22·8	29·7	35·1	100
	− 4	13·5	21·6	27·8	..	96
	−112	12·2	19·5	24·5	28·9	85

rolled bar-irons at 112° F.; but that all the other qualities were more or less prejudicially affected at the lowest temperatures.

H. B.

Steel-Wire Winding-Ropes at Pribram.

(Stahl und Eisen, 1895, p. 645.)

At the Kaiser Franz Josef shaft at Pribram, which is more than 1,000 metres deep, round wire ropes of tapered section are in use made of extra quality crucible steel wire of the highest attainable tensile strength (115–120 tons per square inch). The full number of forty-eight wires is maintained throughout the whole length of the rope (1,250 metres), the taper being obtained by altering the size of wires at intervals, those in the first length of 300 metres being of No. 25 metrical gauge, or 2·5 millimetres diameter; in the three following lengths of 200 metres they are

successively of Nos. 24, 23 and 22; while the last 350 metres are of No. 21, giving the total diameters of 29·5 millimetres at the thick and 23·5 millimetres at the thin end of the rope. The breaking strain of the former section is 41·7 tons, and of the latter 29·5 tons. The weight of the whole rope is 48 cwt., and the average working life 36·6 months, with a useful effect of 28,273,000 foot-tons lifted.

The wire used in these ropes is both of English and German manufacture, and the quality has improved very much during the past ten years, as will be seen from the following Table of average values of the tests of the material supplied at different dates:—

Gauge No.	Origin.	Date.	Resistance.		Torsion.
			Tensile.	Flexure.	
			Tons per Square Inch.	Bends of 180°.	Twists.
20	English . . .	1890	115·6	14	17
	„ . . .	1894	127·6	14	27
	German . . .	1894	111·8	14	25
22	German . . .	1885	112·4	12	12
	English . . .	1890	121·3	12	16
	„ . . .	1894	127·0	12	21
	German . . .	1894	125·1	10	21
25	German . . .	1885	114·9	8	5
	English . . .	1890	118·1	10	15
	„ . . .	1894	125·1	10	21
	German . . .	1894	123·2	10	13

Both kinds are now nearly equal as regards tensile strength and flexibility, but the German wire is still behind the English in toughness as shown by the torsional test. They are both equally susceptible to deterioration by shocks and rust.

H. B.

On the Temper of Extra Hard Steel. By F. Osmond.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 684.)

A bar of steel is prepared by cementation in such a manner that the percentage of carbon varies regularly from one end to the other. It is then hardened and polished, and an ordinary sewing needle drawn along its surface. The Author finds that the needle will scratch the steel as far as the part which contains about 0·7 per cent. of carbon, at which point the mark ceases, but reappears where the percentage of carbon is greater than 1·3. Under the microscope the latter portion of the scratch is found to be discontinuous, proving that the steel is not homogeneous. Steel containing 1 per cent. of carbon is composed almost exclusively of

the harder constituent, the proportion of the softer metal increasing until the carbon reaches 1·6 per cent., beyond which carbide of iron begins to separate. By using steel containing 1·57 per cent. of carbon heated to 1,000° C. and quenched in ice-cold mercury, the two varieties of metal may be obtained in equal proportions. Such a mixture was found to have less power of receiving and of retaining magnetization than a similar sample heated only to 800° C.

G. J. B.

On Testing Steel for Marine-Engine Construction.

By — Auscher.

(Annales des Mines, vol. viii., 1895, p. 564.)

At the French Government Engine Works at Indret the steel used is classified under three heads, namely, (1) semi-hard (32 tons to 35 tons tensile strength with 20 per cent. elongation) in the forms of hammered blooms and hexagonal bars; (2) castings to pattern; and (3) soft (25 tons to 29 tons tensile with 23 per cent. elongation) and extra soft (21·6 tons to 25·4 tons tensile with 25 per cent. elongation), also in blooms and bars. The tensile tests are made with the Thomasset testing-machine, in which the stress is continuously indicated by a mercury column, while the changes in the test-piece are recorded graphically by a registering apparatus designed by Messrs. Richard Brothers, the latter addition being especially useful in fixing the elastic limit—a factor which, for constructive purposes, is of greater value than the ultimate strength. Illustrations are given of some of the curves obtained by this apparatus.

The toughness, or resistance to fracture by impact, is in the harder qualities tested by the falling-weight method, on what is known as the Ruelle machine, where the test-piece—200 millimetres long and 30 millimetres square—laid upon knife-edges 160 millimetres apart and projecting 50 millimetres from the anvil, is subjected to the blow of a falling weight of 18 kilograms, with a rounded end striking midway between the points of support. The minimum weight of the anvil is 350 kilograms, the height of fall and other conditions varying with the class of material. For blooms the whole number,[1] and for bars one-half, of the test-pieces must not break before the fifteenth blow, when the fall is 2·75 metres; while for unforged castings with test-pieces of the same size the initial fall is 1 metre, which is increased progressively by increments of 5 centimetres to a maximum of 1·5 metre, the half limit of resistance being applied as in the case of bars. Soft steel is tested for toughness by the forge test of doubling under the hammer when water-hardened. The Author considers

[1] This seems to be five.—H. B.

these tests, especially the last, to be essentially unsatisfactory, as so much depends upon the degree of heat employed. If the metal is too cold the hardening effect of the water is nil; while if the proper heat (about 900°) is used, the structure is so much changed that the test may be satisfied even by steel originally of bad quality. He therefore proposes to modify the falling-weight test that it may serve both for breaking and bending uses. In this method the test-piece—20 millimetres square—is clamped in a holder with an overhanging length of 100 millimetres, which receives the blow of the tup on its outer end. The bar is nicked on all four sides in the plane of the outer face of the holder, and when so weakened it can be broken by a single blow of the weight falling from a height varying with the quality of the metal, and which is called the height of rupture. If, however, the section is not weakened by grooving, the overhanging part is merely bent by the blow, and the angle of deflection produced is taken as a measure of the rigidity of the metal. This angle may be from 140° to 160°.

The Author considers that steel in the "natural" state is sensibly brittle, whatever may be the amount of carbon contained, and that a soft or extra soft metal giving 25 per cent. elongation is not sensibly safer against breaking than the stronger but less ductile kinds of 30 tons to 38 tons tensile strength, and that the latter should be preferred for moving parts, subject to wear from friction, such as piston-rods, guide-blocks, slide-valve faces, &c., as many accidents to engines on service have arisen from the use of piston-rods made of steel of too soft a quality. In all cases the metal must be subjected to the process of double-tempering (*double trempe*), *i.e.*, a first tempering from a bright cherry red, to effect the transformation of the grain, followed by a second from a dull red, which is more properly annealing, for bringing down the hardness to the required degree, and removing strains producing brittleness. The effect of this process in modifying the fragility and elastic limit in forged steels of the two classes is shown in the following results, obtained by tempering the test-pieces in water at about 170° F.:—

	Soft.		Semi-hard.	
	Natural.	Tempered.	Natural.	Tempered.
Elastic limit . . . . . tons	12·0	20·3	16·0	26·7
Height of rupture . . . . metres	0·2	2·0	0·2	1·8
Angle of bend . . . . . degrees	143	153	151	158

In a second series of experiments the bloom was reduced under the hammer to two-thirds of the original section, with the result of rendering it more homogeneous, which, without altering the

ultimate strength and elastic limit, has a very marked influence on the elongation, and more particularly upon the contraction, which not only became larger but also more regular, being for semi-hard steel when

	Forged.		Natural.
Non-tempered—elongation	24–25 per cent.	instead of	13–16 per cent.
Tempered „	17–18 „	„	7–11 „
Non-tempered—contraction	70–80 „	„	14–24 „
Tempered „	141–163 „	„	22–70 „

The method of double-tempering is now applied at Indert to all forgings for engine work, and, with the exception of the larger engine framings, to most of the castings. A further advantage in its use for these is that cracks are more readily seen when the metal is heated, so that there is greater certainty in detecting unsound castings. The tempering plant is capable of handling objects not exceeding 6 metres in length. Screw-shafts are received forged and tempered at the makers' works (Creusot and Saint Chamond) subject to the following conditions:—

The shafts of steel, either tempered and annealed or double-tempered, must satisfy the following tests: Two sets each of five test-pieces to be taken from slabs cut out of a waste piece of the full size of the shaft and parallel to its length, those for tensile and elastic limits being 100 millimetres long by 13·8 millimetres square, and those for impact 20 millimetres square and not less than 180 millimetres long. These are to be cut to shape cold, and if any of them are unsound others may be cut from the same slabs; but should these be defective the article may be rejected. Three out of the five pieces are to be tested for elastic limits, and incidentally for tensile strength and elongation; but these latter tests are not material. Should the elastic limit of any one be below 28 kilograms per millimetre, or that of the mean of the three below 30 kilograms, the other two shall be tested, when, after rejecting the lowest of the five, the average of the four must not be below 30 kilograms or any one below 28 kilograms.

For the impact test the bars are to be scored on all four sides, at a distance of 100 millimetres from one end, by a cutter of the form of an equilateral triangle of 1 millimetre in the side, made very exactly to gauge. When clamped in the holder by a length not less than 80 millimetres, the piece must not break under a single blow of a weight of 18 kilograms falling 3 metres. Should any one of the three pieces fail the test is to be extended to the remaining two.

Any article not satisfying the tests specified above may, after retempering and annealing, be subjected to a second trial.

These conditions, which are perfectly satisfactory to the manufacturers, are especially valuable as giving a precise idea of the practical value of the material, and have also led to a considerable reduction in the number of test-pieces required in carrying on the current work of the establishment at Indret.

H. B.

The Action of Silicon on Iron, Chromium and Silver.

By Henri Moissan.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 621.)

The Author has studied the action of silicon at high temperatures upon various metals, notably iron, chromium, and silver, which were selected for special investigation after a number of preliminary experiments. He found that by heating iron in contact with crystallized silicon in a porcelain tube traversed by a current of hydrogen the two elements could be brought into combination, although the temperature did not reach the melting-point of iron. The ingot, which was of a silvery-white colour, was hard and brittle, and was composed of a crystalline silicide of iron, embedded in an excess of the metal. He considers this result to indicate that the vapour-tension of silicon at a temperature of 1,200° C., though small, is sufficient to enable the metalloid to combine with the iron by a process analogous to that of cementation, forming with it an alloy more fusible than either constituent. Boron has already been shown to possess this property. Similar results may be obtained more easily with the electric furnace, using charges either of iron and silicon, or of silicon and oxide of iron. In the latter case silicon dioxide is formed and volatilized by the high temperatures employed. In an ordinary forge, although the heat is sufficient for the reaction, it is retarded by the formation of a film of oxide and nitride upon the silicon. The ingots formed, after treatment with dilute nitric acid, left in all cases a crystalline residue, easily attacked by hydro-fluoric acid, and having the formula $SiFe^2$. Chromium, treated in a similar way, formed the analogous compound $SiCr^2$, the experiment succeeding in a reverberatory furnace, as well as in the electric arc. Chromium silicide resembles silicide of iron in its chemical properties, but is harder, scratching quartz and even corundum with ease.

The behaviour of silver towards silicon was entirely different. The fused metal dissolved the silicon with ease, but it crystallized out on cooling.

G. J. B.

The Analysis of Aluminium and its Alloys. By Henri Moissan.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 851.)

This Paper contains a full description of the methods adopted by the Author for the analysis of commercial aluminium. He states that the quality of the metal has been greatly improved within the last few years, but that in all cases mechanical as well as chemical tests should be employed.

G. J. B.

On the presence of Sodium in Aluminium prepared by Electrolysis. By Henri Moissan.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 794.)

The Author has already shown [1] that small quantities of nitrogen and carbon in aluminium reduce its tensile strength. Recently he has found that the presence of sodium is not at all unusual, and is very detrimental. The analyses were effected by digesting in an aluminium vessel 250 grams of the metal in the form of filings with 300 cubic centimetres of water distilled in an aluminium retort. After continuing the process for a fortnight, the liquid was filtered and found to be slightly alkaline. Further treatment with hydrochloric acid gave a substance possessing all the characters of sodium chloride, and amounting to from 0·1 to 0·3 per cent. of the metal employed. Other chemists have also detected sodium in aluminium, Moissonier in particular having found as much as 4 per cent. in one sample. Aluminium containing sodium is attacked by water, at first slowly, but afterwards with increasing rapidity, especially if the quantity of water is small. This is due to the successive formation and decomposition of aluminate of soda. The source of this impurity is considered by the Author to be the cryolite used in the extraction of the metal.

It has been stated by Riche [2] that an alloy of aluminium and tin decomposes water at the ordinary temperature. This was not the case of an alloy prepared by the Author with 6 per cent. of tin and 94 per cent. of aluminium free from sodium, the action of water on it being to form the oxide slowly without any evolution of hydrogen. Alloys with tin are, however, not suitable for soldering aluminium, which should be used as far as possible by itself, and not in contact with any other metal. The presence of impurities of any kind seriously affects its durability.

G. J. B.

Secondary Batteries with Plates of Shuttle Form.

By C. Margaine.

(L'Industrie Électrique, 1895, p. 500. 6 Figs.)

The Author compares pasted plates with the original Planté type, and states that in the former type the difference between the paste and the support causes rapid deformation, the contact being always imperfect. Such plates cannot increase in capacity as time goes on, but are at their best just after formation. The

[1] Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix., 1894, p. 12.
[2] Journal de Pharmacie et de Chimie, 6th series, vol. i. p. 5.

Author considers all such plates much inferior to those of the Planté type, believing that the only method to obtain good cohesion between the peroxide of lead and the lead itself is to form the former from the latter by either a chemical or electrolytic process.

In the Blot type the plates consist of a series of shuttles. Each shuttle is composed of a core of metal which cannot be "formed," and soldered to the frame, which is also of alloy, and is not acted upon. Around the core are wound two thin ribbons, each 0·02 inch thick; one of these ribbons is of lead goffered and striped, and the other of a less oxidisable metal or of pure lead goffered only. In this way an active surface of 1·63 square foot is obtained per lb. of lead, and the conductor is extremely porous owing to the special method of construction. Each shuttle is sawn in half crosswise, and each half forms a single element of a plate. The unit plate consists of eight half-shuttles, fixed in a frame by means of non-oxidisable soldered joints.

The plates are kept separate by glass tubes, and the whole set is hung upon a metal cradle which itself rests upon the glass vessel containing the electrolyte.

The Author states that he has never found the capacity of the cells less than 4·55 ampere-hours per lb. of plates at the normal rate of discharge of 4·55 per lb., and this capacity increases with the use of the cell to 8·63 ampere-hours per lb. Tests were made at the Laboratoire Central d'Electricité which gave results in accord with the Author's statements.

The capacity of a unit plate was found to be 72 ampere-hours (5·45 ampere-hours per lb.) on 12th March, 1895, and had risen to 81·5 ampere-hours (6·3 ampere-hours per lb.) on 25th May, 1895.

On the 25th of November, 1894, a battery was put up in the works of Mr. Blot, consisting of four cells, each containing three negative and two positive plates, weighing 16·5 lbs. per cell. These cells were used to supply current for soldering work which required a discharge of from 80 amperes to 200 amperes, or from 5 amperes to 11·4 amperes per lb. of plate.

On the 3rd of May, 1895, after five-and-a-half months' work, the battery was taken to pieces for examination, and was found to be in perfectly good order; the same battery had continued to work since the 8th of May, 1895, without showing signs of buckling or loss of material. When the Author wrote, these cells had been in constant use for eleven months.

The Author then goes into theoretical calculations as to the possible life of such cells, and considers it would be a long one.

E. R. D.

Gas Batteries. By C. J. Reed.

(The Electrical World, New York, vol. xxv., 1895, p. 419 *et seq.*)

The Author considers that the gas battery is the most promising means for the direct production of electrical energy from fuel; and the investigation described was undertaken with a view to determining the conditions under which hydrogen and other fuel gases would combine with oxygen and to what extent. Reasons are given for the necessity for the employment of electrodes and electrolytes that do not themselves undergo changes during the experiment; and the Author considers it necessary also to exclude a two-fluid cell on account of the difficulty of finding two electrolytes that do not give a considerable electromotive force with incorrodible electrodes when separated by a porous partition. Such a cell is described in which the electromotive force was as high as 1·84 volt. The reactions were therefore investigated with the gases in contact with dilute sulphuric acid and a pair of incorrodible electrodes. An account is given of four experiments.

In the first, platinum electrodes, 2·44 inches long, $\frac{1}{2}$ inch wide, and 0·001 inch thick, were soldered respectively to platinum wires 0·016 inch thick with pure gold. They were then inserted in separate glass tubes 0·55 inch internal diameter and $5\frac{1}{2}$ inches long, the wires being sealed into the glass 0·39 inch from the foil. The tubes, after being cleaned, were filled with dilute sulphuric acid, having a specific gravity of 1·125, and inverted in a beaker of the same solution. One tube was filled with hydrogen, the other with oxygen, to a point about $\frac{3}{8}$ inch above the lower end of the foil by electrolytic decomposition of the sulphuric acid. The tubes and beaker were then heated for about ten minutes to destroy any ozone and hydrogen peroxide, and, after cooling to 20° C., the height of the liquid was marked on them. The terminals were then connected to a Weston voltmeter having a resistance of 356 ohms, each division representing 0·02 volt, and on closing the circuit a throw of half a division obtained, the needle returning instantly to zero or nearly so; there being possibly a deflection corresponding to 0·0005 volt. On opening the circuit for five seconds and again closing it, the same throw was observed, and this could be repeated indefinitely with uniform results. Even supposing the current corresponding to the estimated permanent deflection on closed circuit existed, the output of the cell was, the Author points out, exceedingly small. The cell was short-circuited, the total resistance being 6 ohms and left for five weeks, four observations being taken at intervals during that time. The Author shows what alteration in volume of the gases might have been expected, but, instead of conforming to this, the alteration observed was such as would be fully accounted for by Dalton's law of solubilities; hence, if there be any energy at all evolved by the cell, it is not derived from the combustion of the hydrogen and oxygen.

In the second experiment, exactly similar apparatus was employed, but a current of 1 ampere was passed in by the plates and kept on until the hydrogen formed depressed the liquid in the tube to a point about $\frac{3}{8}$ inch from the bottom of the foil, the other tube containing about half this volume of oxygen; the cell was thus treated as an accumulator. On closing the cell through the same voltmeter as before 0·75 volt was recorded, falling to 0·04 volt after ten seconds and 0·035 volt after twenty seconds, and continuously decreasing until after six hours it was estimated to be 0·0005 volt as in the first experiment. At the end of forty minutes the circuit was opened and quickly closed, a throw corresponding to 0·1 volt being observed, rapidly falling to 0·001 volt. At the end of the six hours the circuit was opened for five seconds; and, on closing it again, a throw of half a division was found, showing that the cell had arrived at the same condition as in the first experiment. Hence, the Author concludes that the action was that of a cell for at least half an hour, and he supposes that the energy, the total amount of which could hardly have exceeded 0·052 ampere-second, was due to the combination of ozone or hydrogen peroxide with hydrogen, or else to some reversible change in the platinum foil due to electrolysis and not to the combination of hydrogen and oxygen.

The third experiment consisted in employing hydrogen prepared by treating pure zinc with dilute sulphuric acid, the gas being washed with argentic nitrate and sodic hydrate, instead of by electrolysis, and air instead of oxygen, the apparatus being the same as before. The action appeared to be the same as in the first experiment. The cell was short-circuited for eight days, and a small diminution of the hydrogen noted, but even if due to combustion, it may not have been that of hydrogen and oxygen, since nitrogen was present, and it may have combined with the hydrogen, especially since it has been shown that these gases combine under the silent discharge.

The fourth experiment was made in a similar manner to the first, except that the foil and wires were coated after sealing the tubes with platinum black, formed by plating them with zinc and immersing them in a solution of platinic chloride containing an excess of hydrochloric acid; about 0·154 grain was deposited on each foil. The cell, on cooling after being heated as in the first experiment, was short-circuited; after five hours the hydrogen had diminished so much that the solution reached the top of the foil and the oxygen to about half that extent. At the end of four days all the hydrogen had disappeared except a small bubble, which at the end of seven days appeared no smaller; it was therefore considered to be nitrogen. Without removing the bubble, the tubes were refilled three times with the same result, the residual bubble increasing in size each time. The cell was then emptied and set up with fresh solution as before, and connected through the voltmeter, the reading, which was 0·85 volt at starting, fell to 0·6 volt after ten seconds, and dropped con-

tinuously to 0·486 volt at the end of 145 minutes, rising then to 0·5 volt when the cell was shaken. By moving the tubes the pressure of the gas was altered, the electromotive force increasing as the pressure was increased. The solution was next diluted with 5 per cent. of water, when the reading fell rapidly to 0·46 volt and in fifteen minutes to 0·455 volt. The circuit was then opened for half an hour and then closed, when the initial reading was 0·85 volt as before, falling to 0·06 volt after nineteen hours.

The Author concludes that the galvanic action depends on the surface of platinum black exposed to the gas, and that a constant current and electromotive force could be maintained indefinitely by exposing a constant area to the gases at constant pressure. He points out that the efficiency of the cell may exceed 33 per cent.; and he thinks one might be constructed to give 80 or 90 per cent. The difference between the behaviour of ordinary platinum and platinum black must be due, in his opinion, to some qualitative difference between them.

C. H. W.

The Regulation of Accumulators at a Distance. By — Aliamet.

(L'Électricien, 1895, p. 321.)

The Author refers to the difficulty of maintaining constant voltage on low-pressure systems of electric supply, and of the advantage which accumulators have as regulators of pressure. It is necessary, however, when a battery of accumulators is used to regulate the pressure, that the number of cells in circuit can be varied easily and with rapidity. A description is given of the well-known accumulator regulator, which consists of a series of contact-blocks connected to successive cells and two parallel bars, one of which is connected to the line direct, and the other through a resistance. Two bridging contacts are then used, one of which bears on each of these bars, the other two ends successively making connection with the batteries' contacts. In this way the current is never interrupted, and by suitably adjusting the resistance interposed between the two bars, the increase or decrease in voltage as the regulator is moved can be made equal to 1 volt. The Author then considers the number of regulating cells required at ordinary pressures.

If the accumulators are small, the regulating gear can be conveniently placed on the switch-board, but when, as in most central stations, large currents have to be dealt with, the connecting cables to the accumulators from the switch-board become a serious item. This is so because every cable has to be capable of taking the maximum current of the accumulators. The Author describes means by which the regulation can be effected from the switch-board or even farther away, the regulating gear being placed in the accumulating-room. The apparatus described was

designed and constructed by the Société Alsaciennes de Belfort for the supply-station of the Place Clichy, in Paris.

In the first arrangement the regulating contacts and bars are arranged horizontally, and the moving cursors are actuated by means of worm gear driven by a small electric motor.

Spur-gearing is used between the motor axle and the wheel driving the main screw to obtain the necessary reduction in speed. A series motor is used, and the direction of rotation is varied by reversing the direction of the current round the field magnets. The principal faults of this system were that the momentum of the motor armature was apt to move the regulator after the current was stopped. In fact, a magnetic brake had to be employed; also considerable sparking was experienced when the circuit was broken. A second arrangement has been more satisfactory. In this the contacts and bars are arranged vertically, and the power for moving the cursors is obtained as follows:—A small motor drives at a low speed a horizontal shaft at the top of the apparatus. On this shaft are fixed eccentrics which give a vertical reciprocating motion to two long racks extending the full length of the apparatus. The pitch of the teeth in the rack, and also the motion of the bar, are equivalent to the space through which the cursor is required to be moved to vary the pressure by 1 volt. The cursor is then made to engage with this rack by means of two pawls actuated by electro-magnets; one of these causes the pawls to engage with the rack as it is moving in the upward direction, and hence increases the number of cells in circuit. The other electro-magnet controls the pawl shaped in the inverse direction, which moves the cursor down and decreases the electromotive force of the circuit. The Author also describes the means employed of indicating at the switchboard the number of cells in circuit at any instant. The article is illustrated by a series of diagramatic sketches and views of the actual apparatus.

R. W. W.

Residual Charges of Condensers. By A. S. Dunstan.

(The Electrical World, New York, vol. xxvi., 1895, p. 3.)

The Author's object was to ascertain the effect on the residual charge in condensers having mica for dielectric, when the potential of the charging-battery and the time of charging were varied and also the effect of previous charges.

A water-battery, connected through a Kempe condenser key, was used for charging, and the two sides of the condenser, one of which was kept permanently to earth, were connected to a Kelvin quadrant electrometer through the usual reversing key. The instrument was furnished with a flat mirror, and the deflection measured by observing the image of a scale reflected by it with a telescope. One set of quadrants were connected to the case and to

earth. When the lever of the reversing key was in one position it discharged the condenser, and when in the other it connected the two sides of the condenser to the quadrants. The condenser was charged for a known time, then insulated and discharged at the same instant; after a known period, the condenser was again insulated and connected to the electrometer, at the same instant a key being depressed which was in connection with the recording mechanism of a Duboscq chronograph; this gave the starting-point of the experiment, and as each centimetre division of the scale passed the fiducial mark of the telescope the key was tapped, so giving a record of the time of the observation. In this way a curve connecting the potential and the time was easily drawn. The constant of the instrument was determined by means of two Carhart Clark cells. In order to avoid errors from damping of the motion of the needle by the acid and the effects of its inertia, the conditions were so chosen that the rate of development of the residual charge was very slow. The two condensers used were as nearly alike as possible, made by the same maker, and the dielectric was mica. The capacity of each was one-third of a microfarad. The temperature was maintained as constant as possible throughout the experiments.

The number of charging-cells was varied from fifty to three hundred and fifty by steps of fifty, the condenser being charged for five seconds and discharged for ten seconds in each case. It was found that a given fraction of the maximum residual charge was attained sooner as the number of cells was increased, and that the maximum value reached was directly proportional to the number of cells.

The time of charging was next varied, the number of cells being kept constant at forty-six, the time of discharge being ten seconds as before. It was found that a given maximum residual charge was attained much more slowly than when more cells were used; the final charge was not proportional to the time of charging, and the Author was unable to determine the law followed.

The Author next charged the condenser for different periods, ranging up to 180 seconds, short-circuited it for sixty seconds, then charged it in the opposite direction for ten seconds, and, after short-circuiting it for ten seconds, determined the residual charge as before. The treatment was applied to both condensers. The longer the duration of the initial charge, the greater its effect on the residual charge, and the Author found that, while the total residual charge is diminished by the charging in the opposite direction, its rate of development is increased thereby. He comments on the difficulty of obtaining a condenser in an entirely neutral condition.

Curves are given expressing the results of all the experiments described above.

C. H. W.

On a New Determination of the Relation between the Electrostatic and Electro-Magnetic Units. By D. Hurmuzescu.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 815.)

The method used by the Author was a modification of that of Maxwell. The electrostatic attraction, due to the difference of potential between the two ends of a known resistance, was measured by means of an absolute electrometer, and balanced by the repulsion between the coils of an electro-dynamometer produced by the same current. The movable systems of the two instruments were rigidly connected and suspended by a very fine fibre, the deviation being brought to zero by adjusting the resistance. Details of the apparatus are appended, with special reference to possible sources of error. The electromotive force employed varied from 1,500 volts to 2,500 volts, and the result of four series of experiments, each consisting of twenty observations, gave for v a value of from $3{\cdot}0005 \times 10^{10}$ to $3{\cdot}0020 \times 10^{10}$.

G. J. B.

A Condenser Telephone-Receiver.

(The Electrical World, New York, vol. xxvi. 1895, p. 195.)

The instrument consists of a rubber case containing a small circular condenser composed of a number of annular sheets of tin-foil separated from one another by manilla paper. Each sheet has a lug, the lugs of alternate sheets being brought together, each set making contact with a separate metal strip on a wooden ring made in two halves which clamps all the sheets together on their outer edges. These strips make contact with the terminals of the instrument when the condenser is slipped into its case. No diaphragm is employed, and no adjustment of any kind is required. The best results are obtained when the sheets lie loosely together, and this is secured by the wooden clamping-ring which causes the sheets to buckle slightly in the centre and so become separated from one another.

Another form of the receiver takes the shape of a book having tin-foil sheets pasted on its leaves, alternate sheets being connected together. The sheets being clamped together at the "bound" edge and lying apart at the edges, the same result is attained as in the circular form by clamping the circumference. The book form is said to act equally well whether it is hanging from a cord or is lying open or is rolled up in the hand.

Any transmitter may be used with this receiver, but the inventor, Mr. Marshall, prefers a carbon one of his own design. The transmitter, with its usual single cell, is connected to one circuit of an induction-coil having three windings; the second coil is connected, one end to earth, the other to the line, and the

third coil is connected in series with the condenser-receiver and a fairly powerful battery. The same arrangement is made at the other end of the line. In order to avoid having the battery at both ends of the line, an alternative arrangement may be used by which the battery is put in series with the line which is then connected through one winding to the condenser, the other terminal of which is connected through the second winding to earth; the transmitter is connected to the third winding as before.

It is stated that the receiver gives excellent results, conversation having been carried on quite clearly through a telegraph line between St. Paul and Duluth, Minn., in the circuit of which were a number of relays, and through which no sound was transmitted when ordinary receivers were employed. In another case the receivers were tried on a line between Albany and Saratoga Springs, and the receivers were laid on a table with the result that all persons in the room could hear the conversation distinctly. It is said that with the book form the sounds are perfectly distinct 12 or 15 feet away, and that if one of these receivers is held to one ear and a circular one to the other, conversation through an artificial line of 200,000 ohms' resistance is unpleasantly loud.

C. H. W.

The Electric Lighting of the Munich Central Railway Station.

By M. Klug.

(Elektrotechnische Zeitschrift, 1895, p. 761 *et seq.* 10 Figs.)

In April, 1893, the Directorate of the Royal Bavarian State Railways invited tenders for the electric lighting of the central station at Munich on the west side of the Hacker bridge, and stipulated that the arc-lamps for lighting the lines should be of the direct-current type placed six in series, while for the indoor-lighting arc- and glow-lamps of the alternating type should be used. On this plan it was found possible to light the whole area, which is 2·66 miles long, from a single generating station without excessive cost for mains. The railway authorities gave the site and built the structure. The sanction of the Government was obtained for the whole project in January, 1894, and meanwhile a temporary lighting of the goods sidings at Laim had been carried out by means of thirty arc-lamps of 16 amperes each by Messrs. Siemens & Halske of Berlin. The dynamos were driven by three horizontal compound engines built by Messrs. Maffei of Munich. Each was capable of developing 140 HP. with steam at 130 lbs. pressure. A surface condenser of the Theissen type is used capable of dealing with 8,800 lbs. of steam per hour.

Messrs. Siemens & Halske were entrusted with the whole of the electrical work for the complete scheme. According to the

specification each alternator was to be mounted upon the same spindle as a direct-current machine, and the two dynamos driven by a single belt actuated by one of the engines, so that by merely lifting the belts off the alternators could be used as motors to drive the direct-current machines.

Arrangements are made to disconnect the machines in case of accident, and they are moved together for belt adjustment. The base-plates are bolted together, and a Raffard elastic coupling connects the shafts and acts as a driving pulley. Each machine is designed to give 20 per cent. above its normal output in case of need for a short period. The installation has been made of ample size and consists of three sets, each comprising an alternator of 51,000 watts at 2,000 volts, and a direct-current machine of 35,000 watts at 330 volts. The exciting current for the alternators is obtained from the direct-current machines, and the speed is 420 revolutions per minute. One complete set is kept in reserve. The alternators will eventually have a third winding put on; steam-power will be done away with, and three-phase current will be used from the water-power electric plant on the River Isar. Each set will then act as a converter changing the polyphase current at 2,000 volts into direct current at 330 volts, so that the advantage of direct-current arc-lamps over the lines may still be obtained.

The alternators have each fourteen poles and fifty alternations per second. The metal parts show a rise of temperature of 72° F. over the surrounding air after a run of sixteen hours.

The potential of the alternators is measured from a special winding on the fixed armature which bears a known ratio to the total potential.

As the dynamos are insulated from the ground by impregnated wooden beams, there was a danger that, if the insulation of the parts of the machine which carry the current were injured, the mere touching of the metal frame of the machine might become dangerous. In order to counteract this danger, the iron of all the machines is connected by an insulated copper wire, and a resistance of high self-induction, consisting of a low-pressure transformer with oil insulation, is inserted in the circuit which is then connected to earth. In the secondary winding of the transformer a signal bell is fixed so as to give warning to the attendant. This apparatus also acts as a lightning protector.

Patent lead-covered cables treated with asphalt are used and carried underground. A peculiarity of the switch-boards is that all cut-outs are collected on the back of the boards; if placed at the front of the boards, they may when melting cause injury to the attendant. An ampere-hour meter for alternating current suitable for 2,000 volts and fifty amperes, and a direct-current meter for 200 amperes and 330 volts are used.

In the original a diagram is given of the connections upon the switch-board, and the Author states that there are two circuits for high-tension feeding transformers of 2·5 to 20-kilowatt capacity

transforming from 2,000 to 120 volts; and there are nine high-tension direct-current circuits.

The arc-lighting indoors is carried out by means of nine-ampere lamps three in series. The outdoor direct-current arc-lamps are for sixteen amperes and burn for eighteen hours, six in series; these are hung upon iron trellis poles 59 feet high, and each can be lowered or raised by a small windlass.

The high-tension leads are carried on treble bell porcelain insulators, and wire netting is hung below the leads and connected to earth, so that in case of breakage of the leads there would be no danger.

The total number of lamps appears to be fifty-four arc-lamps of 16 amperes each on the direct-current system, and 1,114 16-candle-power glow-lamps, seventy-six arc-lamps of 9 amperes, and six arc-lamps of 12 amperes upon the alternate-current system.

Everything was in working order on the 26th January, 1895, and has since that date given perfect satisfaction.

E. R. D.

Worm-Gear for Electric Motors. By Emil Kolben.

(Elektrotechnische Zeitschrift, 1895, p. 514.)

The Author discusses the question of relative motor speeds when direct-coupled worm-gear is used instead of chains or ropes, more especially for hoists and lifts, and considers that the proper tendency is to employ comparatively high speeds.

He then deals with the matter more generally, entering also into the history of investigations into the efficiency of worm-gear. Amongst the results obtained he cites the experiments made many years ago by the late Mr. Anthony Reckenzaun, which showed an efficiency of 87 per cent. at full load with a 15-HP. motor working through a triple-threaded worm. The speed reduction was in the ratio of 1 to 8, and the metals employed for the gear—steel and phosphor-bronze—running in an oil-bath. Experiments made more recently by Professor Stodola of Zürich are also detailed. In this instance the diameter of worm was 3·15 inches, and the pitch 3·29 inches. It was geared from a 20-HP. motor to a bronze worm-wheel with twenty-eight teeth, and having a diameter of 14·7 inches, running in an oil-bath. The brake efficiencies obtained for different speeds are set forth in a diagram, the efficiency curves of various loads rising with the speeds and reaching 87 per cent. at 1,500 revolutions with a load equal to 21 useful horse-power.

The Author considers that even greater efficiencies may be obtained by paying attention to the following points:—

(1) Initial speeds should vary, according to the load, from 1,200 feet to 2,400 feet per minute, instead of 100 feet to 400 feet

as usually proposed. Motors of from 2 HP. to 25 HP. usually run at speeds of from 1,600 revolutions to 800 revolutions per minute, and are therefore easily coupled up direct through worm-gear to lift or hoist spindles, machine-tool spindles, tramcar axles, etc., moving at 150 revolutions to 40 revolutions per minute, a single- or double-threaded worm being used with speed reduction of ten- or twenty-fold.

(2) Great care must be exercised to have the gear mechanically perfect so far as machine-cut teeth and threads, polished and hardened surfaces, etc., can make it so. The worm-wheel should be made of phosphor-bronze with iron arms and hub when of large diameter, and of course should run in an oil-bath.

(3) Case-hardened ball- or roller-bearings for the worm axle are likely to help in a material fashion to reduce the friction to a minimum.

Various illustrations of tools and appliances—such as overhead cranes, punching and shearing machines, etc.—equipped with worm-gear by the Oerlikon Company, are given in addition to the diagrams of efficiency already mentioned.

F. B. L.

Electricity Works at La Goule. By Dr. E. Blattner.

(Elektrotechnische Zeitschrift, 1895, p. 473.)

The Author gives in this article a very elaborate account of an electrical installation carried out by the Oerlikon Company in Swiss Jura, which is a type of enterprise apparently common in Switzerland. Water-power at a convenient point is used to generate electricity in quantities sufficient to give light and power to no less than eleven different townships or villages in Swiss territory, whilst six others across the French frontier also share in the supply. The former are served by three lines of high-pressure mains, four by the first, whose length is 5·88 miles; four by the second, 12¼ miles long; and three by the third, 9½ miles long. A considerable area is thus supplied with light and power, the three lines of mains practically radiating outwards in opposed directions. At each village is a sub-station with transformers, etc.: the total transformer capacity is 104 kilowatts, 445 kilowatts, and 210 kilowatts respectively for the three lines of mains.

At the power-house—situated on the Doubs, close to the French frontier—there is a fall of water equal to about 85 feet; and the hydraulic works (including sluice-gates, tunnels, etc.) are arranged for a maximum capacity of 4,000 HP. At present there are installed three Girard turbines of the horizontal type, each of 500 HP., running at 200 revolutions per minute; they are coupled direct to alternators with rotating field-magnets. These dynamos are designed to give 63 amperes each at a pressure of 5,500 volts. Space for a fourth set is reserved, and the entire station thus

equipped with four turbine alternator sets is capable of duplication if and when required. Each machine has its own exciter,—an ordinary bipolar continuous current machine giving 30 amperes at 80 volts at 700 revolutions per minute, and driven by belting from a countershaft worked by bevel gear on the turbine spindle. The alternator periodicity is 50 per second. The weight of each rotating field-magnet is about $9\frac{1}{2}$ tons, its diameter being 8 feet 3 inches; the armature with supports weighs a little more than 12 tons. The switch-boards are divided into three parts, designed respectively for regulating, measuring and distributing the current.

The high-pressure distributing mains radiating from the power-house have a total length of 192 miles, representing a weight of copper equal to about 77 tons. They are of bare copper wire varying in gauge from No. 12 to No. 1, S.W.G., and are carried overhead on wooden poles by means of ordinary porcelain insulators. At the sub-stations transformers are placed in small specially constructed chambers of brickwork; the secondary mains radiating from these are also run overhead for the most part on poles. They are arranged on the three-wire system, and separate sets of mains are employed for the lighting and motor circuits. The motors (of which there are already 129 installed, ranging in size from $\frac{3}{4}$ HP. to 15 HP.) are of the single-phase alternating type, with fast and loose pulleys so that they may be run up to speed before putting on the load.

They are in reality connected across the outer mains of the three-wire system, the middle wire only coming into use when starting. For this purpose, special switch gear is provided with each motor, but not of a complicated type. Current is supplied day and night except for a break of half an hour between 12.30 P.M. and 1 P.M. Six attendants with an engineer in charge are employed at the power-house, the former working in 8-hour shifts.

The prices charged to consumers are as follows:—

Lighting—	
1. In private houses	1*s.* 2*d.* per candle per annum.
2. Outdoor (streets, &c.)	£1 9*s.* 2*d.* per 25-candle-power lamp per annum.
3. For 10-candle-power lamps in watch-factories (installed by the consumer) .	8*s.* 4*d.* per lamp per annum.

Power—	£	*s.*	*d.*
$\frac{1}{4}$ HP. motor per annum	5	12	0
$\frac{3}{4}$,, ,, ...	14	8	6
1 ,, ,, ...	17	18	6
$1\frac{1}{2}$,, ,, ...	25	0	0
2-12 ,, ,, ... per HP.	13	10	0

with special terms for motors above 12 HP.

At present about 1,500 glow-lamps of 10 candle-power, or their equivalent, have been installed.

A large number of illustrations and diagrams accompany the article. F. B. L.

Electric Light and Power Installation at Copenhagen Harbour.

(Elektrotechnische Zeitschrift, 1895, p. 573.)

The harbour of Copenhagen contains four large basins, all tidal, and therefore covers a considerable area, the length of quayage being nearly 2½ miles with a depth of water varying from 24 feet to 30 feet, so that large ships can moor alongside. The whole of these quays are lighted by electricity supplied from one central station, which also provides current for working a number of cranes and elevators in different warehouses (used for grain and general freight), also along the quays.

The power-house contains three water-tube boilers, each having 1,130 square feet heating-surface, and working at 145 lbs. pressure. They supply steam to four vertical compound condensing-engines of the marine type, each of which gives 100 HP. at 210 revolutions per minute. Three of these engines each drive by belting a six-pole continuous-current dynamo, giving 280 amperes at 240 volts, with a speed of 490 revolutions per minute; the fourth serves to drive from a double fly-wheel two four-pole dynamos, giving each 135 amperes at the same pressure with a speed of 730 revolutions. A pressure of 220 volts is used for the motor circuit, but for the lamps fed from this station a three-wire system is adopted, at 110 volts, with a battery of accumulators in parallel in two halves. This battery—having 140 cells in all—has a capacity of 800 ampere-hours. The total length of mains is about 22 miles, laid partly underground (armoured or as bare copper in covered trenches) and partly overhead on poles.

The motor circuits supply current to an average amount of about 170 HP.; the chief purposes for which motors are used include the pumping of water from culverts (below sea-level) in the made ground of the quays, etc.; also continuous conveyors or elevators in the grain warehouse (employing six motors of 15 HP. each); whip cranes outside the warehouse (with two motors of 12 HP. each) capable of lifting a ton at a speed of 90 feet per minute; two endless conveyors in the basement (with two 15-HP. motors); and grain cleaning-plant (one 18-HP. motor). Along the quays are travelling cranes of the "Titan" or span type, running on rails; each of these is provided with two motors, one of 4½ HP. for traversing, and one of 20 HP. for lifting.

With a load of 1½ ton, the speeds of working are 100 feet per minute lift, and 250 feet per minute traverse. The crane-jib projects outwards about 33 feet, and can thus readily cover any ordinary vessels moored along the quay. At other points of the harbour are additional large warehouses in which are installed electric lifts, used both by the employees and for goods, and in which worm-gear is employed for the sake of safety. The motors fitted to these appliances are of 6½ and 12 HP., according to the maximum loads to be carried. The speed of lift is 80 feet per minute with a load of 1½ ton.

To the lighting circuits are connected up 107 arc-lamps of 6, 10, and 15 amperes, and about 2,000 glow-lamps equal to 16 candle-power each.

Twenty illustrations and diagrams accompany the article, and serve to show the chief points of interest.

F. B. L.

The Electricity Station of Zufikon-Bremgarten, Switzerland.

(Schweizerische-Bauzeitung, 1895, p. 62 *et seq.* 20 Figures.)

The electricity-generating station of Zufikon-Bremgarten, a small town in the Canton of Aargau, obtains power from the River Reuss, which there forms a U bend with many rapids. A drowned weir has been thrown across it, and a canal carries the water across the bend, thus obtaining a total fall of 18·5 feet in height. There is a loss of head by friction, &c., of 1 foot, so that the net effective head is 17·5 feet, which, when the output is at its maximum, is reduced to 16·89 feet. With a delivery of 883 cubic feet of water per second and an efficiency of 75 per cent. the turbines develop 1,300 B.HP.

The building containing the turbines and dynamos is immediately at the end of the tunnel, and has a second storey containing dwelling-rooms. The installation comprises four turbines of the double-reaction type, built by Messrs. Escher Wyss, of Zurich; and each develops 325 B.HP. at 115 revolutions per minute. The Author describes the turbines in detail. Besides the four large turbines there is a small one of 34 B.HP. running at 340 revolutions per minute and driving the exciter for the dynamos. The large turbines are regulated automatically, but the small one has only hand-regulation. Each large turbine drives a rotary-current generator fixed upon the vertical turbine-shaft and developing 224 kilowatts.

The potential produced is 2,900 volts for each side, or 5,000 volts resultant. The armatures are stationary, and inside them rotates a magnet-wheel of cast-steel carrying fifty-two poles, excited by a single direct-current winding. There are seventy-eight windings on the armature, and the current has a frequency of fifty complete periods per second. Each generator weighs 20 tons, and has an external diameter of 11·8 feet. The magnet-wheel is 9·79 feet in diameter, and with the shaft weighs about 12 tons.

Each of the two exciters can develop 11 kilowatts, sufficient for three of the large machines, but usually only two generators are fed by each exciter, which is of the drum armature type, developing 130 volts at 600 revolutions per minute.

From the turbine-house are carried two separate lines of cable, one to Zurich and the other to Wohlen. The former is 12·4 miles long, and consists of two conductors, each composed of three wires of 0·3 inch in diameter, and carried upon creosoted wooden posts

39 feet high and 8 inches in diameter at the top. At one point near Dietikon, owing to the proximity of the River Limmat and the necessity for crossing the North-Eastern Railway, it was found advisable to use two lattice towers connected by a cross bridge, and to carry the insulated wires inside this bridge. The whole plant is used for power-supply. There are now three secondary stations in use, the works of Messrs. Escher Wyss & Co., of Zurich, taking about 400 HP., the mills of Messrs. Maggi & Co. about 200 HP., and the central station of the Wohlen Corporation about 80 HP. measured at the motor shafts.

The plant at the works of Messrs. Escher Wyss & Co. is so arranged that the dynamos can either be driven by motors actuated by current from Bremgarten or direct by steam-power. There are here installed two rotary-current transformers, each of 200 kilowatts capacity, and these deliver current at 115 volts or 230 volts, according to the method of connection.

The reserve plant comprises two low-tension rotary-current generators with horizontal shafts, and these can be direct coupled to a steam-engine and driven at 240 revolutions per minute. The Author gives details of the construction of the machines. Besides these there are in the engine-house two six-pole Oerlikon direct-current machines, each for an output of 500 amperes and 120 volts at 480 revolutions per minute. These are used for lighting the factory by means of 130 arc-lamps and 800 glow-lamps. The Author states that the reserve plant and the rest of the plant can be worked in parallel, although the prime movers are 12·4 miles apart. A list in tabulated form is then given of all the motors used in the establishment. Similar details are also given as to the plant installed at the mills of Messrs. Maggi & Co.

The plant at Zufikon-Bremgarten has been at work since the 1st July, 1894, part of the plant at the works of Messrs. Escher Wyss & Co. since the 1st April, 1894, and the rest dates from 1895.

The efficiencies are as follows:—Rotary-current generators, 94 per cent., inclusive of exciting; line to Zurich, 85 per cent.; transformers, 97 per cent.; giving an efficiency at the secondary terminals of 77 per cent.

E. R. D.

An Electric Power-Station on the Loire.

(Comptes Rendus de la Société de l'Industrie Minérale, 1895, p. 249.)

At Saint Victor-sur-Loire, about 7 miles west of Saint Etienne, the Compagnie Electrique de la Loire have established a central power-station, from which the current is distributed to a considerable distance in three different directions. The power is derived from the Canal de Forez, which was made about fifty years ago for irrigating purposes, but which has not as yet been utilized by

the local farmers. The average flow of the canal is about 15 cubic metres per second, about one-half of that of the river at the intake. Upon a fall varying from 8½ metres to 9 metres three turbines have been established, each taking about 8·75 cubic metres per second, giving a maximum effect of about 300 HP. measured on the shaft of the dynamo. The turbines are of the Hercules class, taking the water at the circumference and discharging towards the centre. As, however, the hydraulic motors are subject to interruption, not only during periods of drought when the river-supply is insufficient, but also in heavy floods when it is necessary to shut the sluices to prevent the canal from being silted up, two out of the three groups have been provided with supplementary steam-power. These are Bićtrix compound engines with rotatory slide valves, having cylinders of 400 millimetres and 500 millimetres diameter and 600 millimetres stroke, making 172 revolutions per minute. Steam at 9 atmospheres pressure is supplied by five boilers, each having a heating-surface of 100 square metres. The dynamos of the Oerlikon triphased alternating class are exactly similar to those used in the long-distance transmission from Lauffen to Frankfort, having fixed ring armatures built up of soft iron disks with paper insulations and cast-iron rotating disk magnets with thirty-two pole pieces, excited by a continuous current shunt-wound dynamo driven by a pulley from the main shaft of a large alternator. The primary current is raised by transformers from 50 volts to 3,000 volts for distribution along the main lines, which extend from the station in three different directions, the furthest points reached being St. Galmier, about 12 miles north, La Talandière, 10 miles east, and Aurec, 4 miles south, the total length of lines, including branches to Firminy and St. Heaud being about 35 miles. The greatest length of any branch is about 15 miles. The current, which on arrival is reduced by transformers to 120 volts, is utilized for lighting and power purposes, the district being mainly inhabited by a population of silk-ribbon weavers, who work at their own homes, in small shops containing two or three looms. These are supplied with power at the rate of 11 francs per loom per month, with allowance for time lost when the stoppage is duly certified. For lighting the charge per 10-candle-lamp is from 24 francs to 36 francs per annum, or by metre 6 centimes per hectowatt-hour, corresponding to 2½ centimes per 10-candle-lamp with a minimum annual charge of 1·2 franc per lamp. Public lights are charged 24 francs per annum, the light being supplied from 5 A.M. to sunrise, and from sunset to 11 P.M.

H. B.

The Establishment of Electric Power at Puteaux (Paris).

By J. Loubat.

(La Revue Technique, 1895, p. 440. 11 Figs.)

The Author states that Mr. O. Patin, the well-known electrician, has secured the park of the "Château de Puteaux," near Paris, which has an extent of about 17·3 acres, and proposes to construct a number of workshops around a central station, and to supply both light and power by means of electricity, believing that only by combining the two services can the price of current be notably reduced. Before the station was begun, the demand for light had risen to 5,000 lamps. The park is on the banks of the Seine, and current for electric-lighting has been supplied since last February, although the station itself is not yet perfectly complete. Near the station will be built the workshops which Mr. Patin proposes to erect, and these will be let to manufacturers at reasonable rentals.

Further off are the workshops where the special "Patin" fly-wheel alternators are built. The Author describes in detail the latest form of dynamo built by Mr. Patin.

He discusses the relative advantages and disadvantages of rope- or belt-driving, and direct driving, and sums up by stating that Mr. Patin considers all objections are overcome by making the field-magnets part of the rim of the fly-wheel of a slow-running engine and using a stationary armature.

Viewed in section, the fly-wheel rim is in the form of the letter C, and the armature is in the form of a flat ring which enters the opening in the rim between the field-magnets.

The armature rim is fixed upon a spider with a large boss carried upon a hollow cylindrical support through which the main shaft passes without touching it.

The armature can be moved in or out of gear by means of a screw and ratchet. When in gear a key prevents it from revolving, and when out of gear inspection is easy.

The engine runs at a speed of from 50 to 100 revolutions per minute according to the size of the alternator driven. The fly-wheel really consists of two separate wheels bolted together; the wheel of smaller diameter carries upon its periphery a series of magnets which form the inner ring of poles, while the wheel of larger diameter has an overhung rim with a series of magnets fixed on to its internal circumference forming the outer ring of poles. The number of poles of course depends upon speed and frequency required.

Details are then given as to the construction of the armature. The chief point appears to be that the wire is wound upon gun-metal cores of concave shape to suit the curve of the rim plates.

The above description applies to machines of from 50 to 300 HP., while beyond the latter size the field-magnet ring is double and two armatures are used.

A special form of transformer has also been designed with very little loss at no load, and details of this are given.

The following Table shows results obtained in two different cases by Patin alternators. The figures in the first column were obtained from a machine driven by a turbine with a governor by Faesch and Picard, and those in the second column from a machine driven by a horizontal steam-engine with variable expansion of the Blondel type.

The variation of voltage when the load was suddenly removed was less than 2 per cent.

Power in watts	40,000	120,000
Volts at terminals	2,400	2,400
Current when loaded	16·7 amperes.	50 amperes.
Resistance of armature	4·5 ohms.	0·96 ohm.
Number of poles of field-magnets	24	104
Resistance of field-magnets	4·8 ohms.	0·5 ohm.
Number of armature coils	24	104
„ „ revolutions per minute	300	95
Frequency	60	82
Efficiency	94 per cent.	96 per cent.
Energy spent in exciting	1·2 watt.	2·4 watts.

In the generating station at Puteaux there are three sets of plant: one set consists of a single cylinder horizontal engine of the Blondel type developing 150 HP., fitted with Claetz valve-gear and driving an alternator of 100,000 watts.

The second set consists of a twin compound engine by Blondel fitted with modified Corliss valve-gear of the Frickart type, developing 600 HP. and driving a dynamo of 300,000 watts.

The third set is the same as the first, except that the engines are by Crepelle and Garand. Puteaux alone is at present lighted, but St. Cloud, Garches and Courbevoie will shortly be supplied.

The price of current is 1*s.* per Board of Trade with a discount. The area which can eventually be supplied is 38·5 square miles in extent, and contains 600,000 inhabitants.

An electric tramway worked by alternate current is to be put down in the park at Puteaux, but of this no details are given.

E. R. D.

The Gesundbrunnen-Pankow Electric Tramway (Berlin).

(Elektrotechnische Zeitschrift, 1895, p. 687. 6 Figs.)

On the 10th September last, the first street electric railway in Berlin was opened for traffic from Gesundbrunnen to Pankow. The line starts from the Badstrasse and is about 1½ mile long, mostly of double track, and about 0·56 mile is in the City of Berlin itself. Messrs. Siemens and Halske were the contractors, and they obtained a concession from the authorities at Pankow in April, 1893, for a term of fifty years; difficulty was found in obtaining

permission for an overhead wire in Berlin itself, but it was granted in November, 1894, when the rest of the work was well in hand.

The road is of ordinary gauge, and in Pankow the rails are of the Hörde groove type, weighing 150 lbs. per yard, while in Berlin the same type weighing 190 lbs. per yard is used. At the joints wire connections are used to improve the conductivity. Grades are very easy, and the minimum radius of curves is 82 feet. The overhead conductor is of hard copper 0·315 inch diameter. Its average height is about 16 feet above street-level, and it is carried partly on cross-wires hung from poles placed at the edge of the footway and partly from brackets carried by poles.

The poles are steel tubes made by the Mannesmann process fixed in cast-iron bases set in concrete. The method of hanging the conductor to the iron brackets is worthy of note as it is the system in general use by the contractors; the conductor is hung from a steel cross-wire which is the string of the bow-shaped arm standing out from the post. This method gives good insulation and allows also freedom of movement. The contact-maker is of stirrup form, and this obviates all need for change-over points on the overhead wires, as the width of the stirrup enables it to touch at the same time two conductors which are near together.

Eight cars are now at work, each fitted with a 25-HP. motor of the 4-pole type. The field-magnets are series wound, and form a closed case around the armature which is put in from the side.

The gear is of the single reduction type 1 : 5; the pinion is of bronze, and the wheel of steel, and the gear runs in oil. Speed is regulated by resistance coils, and it averages 11 miles per hour and rises to 15·5 miles per hour. Each car carries thirty passengers. There is only one fare for all distances, and the driver takes the money, so that passengers enter at the front only. At the generating station there are two water-tube boilers by Simonis and Lanz of Frankfort-on-Main; each has 805 square feet of heating surface, and the feed-water is obtained from a well; the working pressure is 150 lbs. per square inch.

The two engines are of a horizontal compound condensing type by the Maschinenfabrik Buckau; they work at 135 revolutions per minute, and each develops 110 HP. The dynamos are each 70,000 watt machines with ring armatures outside the 8-pole field-magnets, and are direct coupled to the engines. The line is fed with current at 800 volts, and at present one engine and one boiler suffice. On Sundays and holidays there is a 5-minute service of cars, and on other days a 10-minute service. The Author hopes that the line will be continued to the centre of Berlin.

E. R. D.

Electric Elevators. By Ernest Egger.

(Elektrotechnische Zeitschrift, 1895, p. 450.)

The limited use of electric hoists in Europe as compared with the United States is largely due to the greater height of the residential and office blocks in the latter country, coupled with the greater complication and expense of hydraulic working. The Author states that with water-compressing plant on the spot, the coal-consumption in a large New York block was 1 ton per day for 4 lifts, making about 1,000 journeys in all, to a height of 150 feet. He gives the maximum speed of "express" elevators (which do not stop at all floors) as being nearly 560 feet per minute; whilst those stopping at each floor run on the average at a speed of from 345 to 400 feet per minute. With electric working—especially when using worm gear—the average speed does not rise above 295 feet per minute. Whilst this may appear disadvantageous, yet there is to be considered *per contra* the comparative simplicity of an electric elevator, the less room required for the gear, &c., together with the greater economy in first cost and working expenses.

The Author describes, with the help of a number of illustrations, the chief methods adopted for operating electric elevators. In the first of these the motor shaft is connected to a worm shaft through a suitable coupling, the worm driving a worm-wheel on the elevator rope-drum shaft. The motor speed is therefore low. A counterweight equal to half the average useful load, plus the weight of elevator cage, is generally employed. Special switching devices are described for reversing and regulating the speed.

According to another method, the motor shaft is extended through a coupling and carries on the extension two coned friction clutches, so that the direction of rotation in the elevator rope-drum may be reversed without reversing the motor. Connection between the clutch shaft and the elevator drum is obtained through belting or chain gear, on an intermediate shaft that carries a worm, gearing into the drum worm-wheel.

A third method somewhat resembles the multiplying gear of an ordinary hydraulic crane, an endless screw and nut being used, however, instead of blocks and a chain. The motor shaft is continued through the usual coupling, and carries a long square threaded screw, on which travels a nut secured to a shaft carrying a drum. Round the latter are passed two or three turns of the elevator rope, which also passes round a fixed drum of equal size to the other, one end of the rope being fastened to the headstock carrying the fixed drum.

After describing one or two other methods, and a variety of regulating switches, &c., the Author concludes by giving some figures as to cost of working, &c. Results obtained in the United States tend to show that for a useful load of 1,500 lbs., the cost of

lifting to a height of 98 feet is $\frac{1}{2}d.$ inclusive of return journey. In Berlin, the cost of lifting a useful load of 850 lbs. to a height of 78 feet is said to be about $0{\cdot}1d.$ inclusive of descent, and taking electric energy supply from a central station at the rate of $2\frac{1}{4}d.$ per kilowatt. This is compared with a cost of $0{\cdot}18d.$ for hydraulic working, pressure being obtained on the spot from a gas-engine and pump, with gas at 3*s.* 6*d.* per 1,000 cubic feet. The cost of working the same elevator under similar conditions with water from the town mains (pressure not stated) is said to be slightly over 1*d.* Figures from elevators erected in Vienna, tend to show a more strongly marked difference between electrical and hydraulic working, the results varying from $0{\cdot}1d.$ to $0{\cdot}2d.$ for the former, and $0{\cdot}4d.$ to $0{\cdot}5d.$ for the combined system of gas-engine and hydraulic pump.

F. B. L.

The Zerener Electric-Welding Process.

[(*a*) Sitzungsberichte des Vereins zur Beförderung des Gewerbfleisses, 1893, p. 211. By Dr. ZERENER.
(*b*) Stahl und Eisen, 1894, p. 772. 1 Fig.
(*c*) L'Industrie Électrique, 1895, p. 359. 2 Figs. By P. GASNIER.]

(*a*) On the 2nd of October, 1893, Dr. Zerener read a Paper before the above Society on "The distortion of the electric arc by magnetism, and electric soldering and welding." He introduces the subject by a history of the work already done by others in the same direction, and refers also to a Paper read before the same Society by Mr. Slaby at an earlier date.

He then refers in detail to his own special work. The electric arc behaves like a movable conductor in the presence of an electro-magnet, but the influence upon the arc does not take place in the direction of the lines of force of the magnet, but in the direction of its molecular streaming, that is to say, in the direction of the windings. The Author succeeded in directing the lines of force of the electric arc as he chose by using a horse-shoe magnet with one pole on each side of the arc in such a position that the lines of force of the arc lay at right angles to the magnetic lines of force. The arc being between the poles of the magnet the latter can exert its full effect. The Author discovered this fact and the relative proportions to be given to the parts only after a long series of experiments.

The arc itself could then be projected downwards in the form of a pointed tongue of flame similar to that produced by a blow-pipe.

The relative arrangement of magnet poles and arc is the one essential point, and is the basis upon which all the apparatus is constructed.

The Author showed the apparatus in actual work before the audience, and pointed out that without the use of an electrical testing-station he could not have made the requisite experiments

as to the required strength of the magnets, necessary windings and connection between the magnet and the arc. He desired to produce an apparatus which could be used not only for welding but also for soldering, as the latter process had not hitherto been possible by means of electricity. It is essential that the work should be done without self-regulating mechanism, which would make the hand-apparatus too heavy.

Details are given of the attempts made to construct a suitable mechanism, which he gradually simplified. The final form consists in placing the carbons in a plane passing through the axis of the handles, the two carbons being at an angle of 30° to each other. One is rigidly attached to the handle and the other can be regulated by means of a screw easily worked by the thumb, and gives good results for soldering. Another form of apparatus has the magnet in a plane passing through the axis of the handle, and the carbons stand in a plane at right angles to it and inclined at an angle of $22\frac{1}{2}$° to each other.

Regulation is effected by turning a milled wheel which can easily be done with the hand that holds the tool, the wheel by means of gearing controlling the rack rods which serve as carbon carriers. Another apparatus consists of a kind of Jablochkoff candle with magnet opposite.

The Author then describes an automatic machine for large work, such as the welding of plates; here the work is moved under the fixed arc. The two carbons are both movable in the direction of their axes, and the position of the arc is kept fixed by means of a right- and left-handed screw. The spindle of the screw is controlled by an electro-motor so wound as to regulate the arc automatically.

With a current of from 40 amperes to 50 amperes and a potential of 41 volts, plate from 0·12 inch to 0·16 inch in thickness can be worked.

(*b*) This article appears to be merely a recapitulation of the foregoing Paper.

(*c*) The Author states in this article that there is as yet no practical application of electric-welding in use in France, but the Zerener process is now being introduced by Messrs. Worms & Zwierschowski. The article is more or less a translation of Dr. Zerener's Paper, but appears to describe the most recent form of the apparatus.

Either alternate or direct current may be used, and the small hand apparatus does not weigh more than 2·2 lbs.; the windings of the magnet are in series with the arc, and the tool works well at 40 volts and a minimum current of 15 amperes; it is used for welding small articles of iron, copper, silver, &c. For brazing, a current of from 40 to 60 amperes is used, and borax employed as a flux; this method has been found very satisfactory for making joints in bicycle frames. A more powerful automatic apparatus is made which needs a potential of 70 volts and a current of from 100 to 200 amperes, when iron plate 0·197 inch thick can be welded.

No battery of accumulators is required, and in fact current from the public mains can be used. The Author states that the process is cheaper than other well-known processes. A soldering iron with copper bit is also made; the carbons are placed at an angle of about 30° to each other, and the two limbs of the horse-shoe magnet are in a plane at right angles to the plane passing through the carbons; this tool requires from 5 amperes at 40 volts to 10 amperes at 60 volts.

E. R. D.

The Slavianoff Electric-Welding Process. By A. Lohmann.

(Elektrotechnische Zeitschrift, 1895, p 325.)

In this article the Author gives a long illustrated description of an electric-heating or welding process, devised by Herr Nicholai Slavianoff, the special advantages of which appear to consist chiefly of its adaptability to the repairs of articles in cast-iron or similar material.

Essentially, however, the process does not appear to differ much from other well-known methods; such, for example, as that due to Benardos, since the principle of working adopted is merely that of an ordinary electric arc, localized in the place where fusing heat is required. Several modes of doing this are described; in one the article to be repaired is connected to the negative pole of dynamo, or other source of electric energy, through a suitable resistance, whilst the positive is connected to an electrode dipping into a mould placed round the defective part and containing small pieces of suitable metal, which are heated by the arc to a proper degree of temperature. Some of the results thus obtained are illustrated to show the adaptability of the process. The special feature of the Slavianoff method appears to be an automatic regulating device for maintaining the arc, just as is done in every arc-lamp. This device the Author describes in detail, but it has no great novelty.

The positive electrode is composed of the same material as that to be melted, and current is required in proportion to the size of electrode, varying from $7\frac{1}{2}$ to 8 amperes per square millimetre (0·00155 square inch) of sectional area. The voltage employed varies from 50 to 70 volts.

F. B. L.

Electricity in the Italian Navy. By Giulio Martinez.

(The Electrical World, New York, vol. xxvi., 1895, p. 397 *et seq.*)

The account, which it is stated is written with the authorization of the Italian Naval Department, gives a full description of the apparatus in use, and the organization of the electrical work of the Italian Navy.

Before the year 1887 the application of electricity was confined to projectors, and little attention was paid to the generators except as regards the space they occupied. It was usual to have one machine to each light, but with the increase in number which soon took place, the poor economy of the system became evident, and as about the same time it was decided to employ glow-lamps for general lighting, it was determined to provide standard apparatus of high efficiency of the same pattern in all ships. A very cogent reason for this course was the fact that the men are all obtained by conscription and remain in the service for a few years only; it is therefore necessary that the apparatus should be as simple and uniform as possible. Men who have been fishermen or carpenters are usually employed to run dynamos, while those who are told off as electricians or torpedo men go through a course of training on a special vessel, and are afterwards distributed among the ships.

At the present time, with the exception of five cruisers, all ships other than torpedo boats have a standard generating plant comprising a compound-wound Brush-Victoria dynamo having a regulating resistance in the shunt circuit, coupled direct through a Raffard coupling, having copper instead of rubber rings, to a Tosi engine which is very solidly built and is of marine type with one cylinder if simple, and two placed tandem if compound. Five sizes are in use, all the dynamos working at the same voltage, 65 volts, and giving currents of 60 amperes and 100 amperes, these being driven by simple engines, and 150 amperes, 200 amperes, and 300 amperes driven by compound engines. The speed varies from 260 revolutions per minute in the largest size to 450 in the smallest. The governor is similar to that in the Westinghouse and Armington and Sims engines and regulates the cut-off; it is very sensitive and maintains constant speed, but it cannot be adjusted while running. With the largest sizes, the steam-consumption at full load, when working at a pressure of 70 pounds to 120 pounds per square inch, is 49 lbs. of steam when working non-condensing, and 40 lbs. when condensing, per useful electrical horse-power (736 watt-hours (*sic*)). Since the efficiency of the dynamo is only about 86 per cent. the steam consumption is about 31 lbs. per indicated horse-power when condensing.

The conductors are made by two Italian firms, and the cables, which are of tinned copper stranded, are usually insulated with rubber protected with "textile" material further protected with lead when exposed to moisture or oil. A standard set of sizes varying from 0·001 square inch to 0·263 square inch has been fixed upon. In the cabins and state-rooms double silk covering is much used. The vessel is not used as a return, and all conductors are run in teak moulding even if lead-covered. In certain cases they are enclosed in an iron pipe made perfectly watertight, with watertight joints at the branches, the wiring in each watertight compartment of the ship being so arranged that if the compartment be flooded, the local wiring only is affected,

the main being intact. Separate circuits are run for projectors, signals, motors and lighting, the last being further subdivided. The circuits are divided into protected and unprotected circuits, corresponding to the protected parts of the ship, and those above the water-line. Not more than seven or eight lamps are controlled by one fuse, the average being three or four. The maximum drop of pressure allowed on the conductors is two volts. Diagrams are given showing the method of wiring, and the circuits on board the "Sardegna" are minutely described. Cut-outs are placed on the switch-board at the beginning of the circuit and at the root of most of the large branches and of all small ones, but never along the length of the main conductors as was done at one time.

The Cruto glow-lamp, of a type specially made for the Italian Navy, is exclusively used, only two sizes being employed, one of 12 candle-power, with Edison base, for ordinary service, the other of 25 candle-power, with a special base, for running lights and signals. The average life exceeds 800 hours; after this period, the light falls off about one-third. The various kinds of fittings in use are illustrated. All the minor accessories are of solid construction, and are manufactured in Italy. The majority of the motors are of the C. and C. type made in Italy by the Edison Swan Company of Milan, though there are many Siemens motors and several other types.

Two types of switch-board are used, both of which are illustrated. The first is formed of vertical and horizontal bars; each vertical bar is in two parts, insulated from one another and connected respectively to the two conductors of a circuit, while half the number of horizontal bars are connected to the positive poles of the dynamos, and the other half to the negative poles. The dynamos are never run in parallel, and sliding shutters prevent the board being plugged so as to preclude the possibility of this being done, or of a short circuit being made. The apparatus is covered in with a glass front. This type of board does not admit of a circuit being changed over from one machine to another without interruption in the current, and it is not suitable for heavy currents; hence in large vessels of the "Re Umberto" class (corresponding to H.M.S. "Royal Sovereign") the second type is used; this admits of certain changes being made in the circuits while running, so that more than one can be run by a dynamo, and the dynamos can be interchanged to a limited extent. A detailed description of the switching arrangements on the "Sardegna" is given; the switches, which are two-way, are of the hatchet type. A practice is made of keeping one machine running slow as a reserve, and this is utilized when changing over circuits, the machine being run up to speed for the purpose.

The switch-boards are provided with magnetic cut-outs so arranged that when the main current exceeds a certain value a magnet attracts an armature which puts a lamp-resistance of 4 ohms in the shunt circuit of the dynamo, so lowering the pressure;

the current then falls and the armature returns, cutting out the resistance and restoring the normal pressure; in this manner the circuit is not opened if the fault exists only for a brief period. Pilot lamps, used also to light the dynamo-room, are attached to the switch-board, and Brush rheostats, particulars of which are given, are provided. The measuring instruments are made by Carpentier of Paris and are dead-beat and unaffected by the motion of the ship, but they require frequent recalibration, for which purpose a Weston voltmeter is used. A careful log is kept of the current supplied.

The projectors are automatically regulating fixed focus lamps on the Pasqualini system and are minutely described; they are of two sizes, 50 amperes and 90 amperes, and all are provided with Mangin reflectors. They can be fed by hand if desired.

Special attention is called to the fact that all apparatus except dynamos, projectors and instruments are made in Italy, and these exceptions are said to arise only from the desire for uniformity, and it is stated that in the near future no foreign apparatus will be used.

The Author concludes with a description of the laboratory of St. Bartolomea at Spezia, which is the most important but not the only one. A plan is given and the work done in the various departments described. This comprises testing of engines and dynamos, also of motors and ventilating fans, standardising instruments, regulation of arc-lamps and testing of carbons, photometric measurements, cable testing, and a considerable amount of original research work. Statistics of the amount of work done are given. A generating station is attached, and a winding department for new work and repairs, together with a workshop for experimental apparatus. There is also a chemical laboratory. A detailed description is given of a method of testing motors devised by Professor Pasqualini.

C. H. W.

Electro-plating Ships.

(The Electrical World, New York, vol. xxvi., 1895, p. 591.)

The advantage of coating the submerged portions of ocean-going vessels with copper, in order to prevent organic growth and corrosive action on iron and steel, is recognised. The process here described is an electrolytic one, by which wooden sheathing outside the iron or steel is unnecessary, the copper being deposited on the metal, and, in the case of wooden ships, on the wood, a preliminary coat of plumbago being necessary for the latter.

The skin is applied to the finished vessel, the method of doing so being as follows:—The surface is first pickled with dilute sulphuric acid for about twelve hours, the liquid being contained in shallow baths of rectangular shape, open at one side, having heavy soft-rubber gaskets on the edges and being made tight with

coal-tar; they are held in position by poles. The surface is then scoured with sand and soda. In order to obtain an adherent coating, two baths are used; the first is a cyanide solution of copper from which the metal is deposited for about twelve hours, copper electrodes, connected to the positive pole of the dynamo, being placed in the baths, while the negative pole is connected to the plating of the vessel. Each bath has an area of about 60 square feet, and the current density is about five amperes per square foot, the pressure being 5 volts. The surface is washed and scratched with steel brushes before the second bath, which is a solution of sulphate of copper, is applied. The current density is the same as before; but the pressure required is only about $2\frac{1}{2}$ volts. The current is kept on for about forty-eight hours, the deposit reaching a thickness of from $\frac{3}{32}$ inch to $\frac{1}{8}$ inch. The electrolyte is pumped by a small steam-pump through two main pipes placed round the ship, two pipes connected to these respectively being carried into each bath through holes in its bottom. A reservoir at one end of the ship and a stand-pipe at the other cause a fairly constant pressure to be maintained.

The process is being carried out by the Ship Copper Plating Company in Jersey City, and a description of the plant used is given.

C. H. W.

Microscopical Research on the Electrostatic Discharge.

By George P. Hanchett.

(The Electrical World, New York, vol. xxv., 1895, p. 389.)

The Author caused the discharge from an induction coil to pass between two strips of tinfoil, pasted on one side of a glass plate, the opposing ends of the foil being pointed. The strips were connected to the two ends of the coil respectively, one being earthed and connected also with the frame of a microscope, used to watch the discharge, shocks from the instrument being in this way avoided. A photographic record of the discharge was made.

It was found that both terminals were diminished in size by the passage of the discharge, but the waste at the negative terminal was the greater. Three figures, prepared from photographs, are given to show this. The waste at the negative terminal seems to be due to heat, while that at the positive appears caused by mechanical tearing away of the material. The Author regards this fact as affording evidence that the actual direction of flow is that which it is conventionally assumed to be, but he comments on the difficulty of determining this, instancing the burring of both sides of the hole when a card is pierced by a spark, and details experiments which showed that the amount of material lost by the positive terminal is very small. He thinks that the difference in the shrinkage of the two pieces of tinfoil is due very largely

to the negative terminal being much more melted than the other, from which he concludes that it is the hotter.

The experiments just referred to were the following:—In order to test whether there were a flow of luminous matter from positive to negative, the Author supported a glass thread, rather less than 20 inches long, rigidly at one end, the other being free and in the field of a microscope with a $\frac{1}{4}$-inch objective. A point on the thread, about two-thirds of the distance from the support (from the illustration, it would appear that it was two-thirds of the distance from the free end), was so placed that it was directly in the path of the discharge from a powerful induction coil, and in a modification of the experiment a small piece of tinfoil was attached to the thread. Means were taken to prevent the vibration of the contact breaker being communicated to the thread. In neither case could any movement of the thread be detected that could be attributed to the discharge. Another experiment consisted in weighing two pieces of tinfoil, and then causing the discharge to pass until the negative piece was almost melted into a ball; they were then weighed again, but no change in weight was observed, though the balance was hardly sensitive enough to make the experiment conclusive.

The Author proceeds to describe the appearance of the discharge as seen under the microscope. Five reproductions of photographs are given, and the conditions under which they were obtained, and their peculiarities described; also the appearance of the discharge when viewed through dark glass.

The Author found that ozone is given off most copiously at the negative terminal; he made a pool of starch and potassium iodide on a sheet of paper, and passed sparks into it from both terminals. The mixture opposite the positive terminal, to which it was, of course, negative, was most blackened in a given time. The blackening was not due to electrolysis, since when both terminals were immersed in the mixture, the current was too small to produce electrolysis, moreover when the current is strong enough to cause it, the positive electrode blackens. It was found that there is much less heat generated at the terminals when the distance between them is a maximum than when it is short.

C. H. W.

Determination of Specific Inductive Capacity.

By Julien Lefèvre.

(Annales Télégraphiques, vol. xxii., 1895, p. 178.)

The method of investigation employed by the Author consisted in measuring the attraction between two plates of a condenser, one of which is movable, the dielectric being first air and then the material under examination. If F′ is the attraction between the plates when the distance between them is $e + e'$ in air, and

F the attraction at the same distance when a plate of thickness e is placed between them, e' being the sum of the thicknesses of the layers of air on either side the plate, and if k is the specific inductive capacity, then

$$\frac{F}{F'} = \frac{e + e'}{\frac{e}{k} + e'}.$$

The Author desired to verify this formula, and a minute description of the apparatus employed is given. The substances tested were sulphur, paraffin, ebonite, petroleum, essence of turpentine and bisulphide of carbon. The sulphur and paraffin were cast in a mould very carefully levelled, and the liquids were placed in a thin glass vessel, the diameter of which, as also was that of the solid plates, was greater than that of the movable plate.

The material having been placed in position, the apparatus was left to itself for several days in order that there might be no trace of electrification. The balance containing a counterpoise a little too light was after this interval brought into exact equilibrium by a weight p. The condenser was then excited by a Ruhmkorf coil, and equilibrium restored by a weight P. The fixed plate was then earthed, and the beam again balanced with a weight p'. The attraction is then $F = P - \frac{p + p'}{2}$. The piece of material under test was then removed, and the attraction F′ measured in the same way. In the case of liquids F′ was determined first in order to avoid evaporation, the glass vessel being placed in position beforehand. The liquid was then poured in, and F measured immediately. The glass at the bottom of the vessel was allowed for by reducing the thickness to the equivalent thickness of air, the specific inductive capacity being assumed to be 2·5.

The measurements are tabulated, and the values of k deduced from them are given. These values are as follows:—

Paraffin No. 1	1·80
„ No. 1	2·15
„ No. 2	2·16
„ No. 2	2·14
Sulphur	2·73
„	2·50
Ebonite	2·32
Bisulphide of carbon	1·63
Essence of turpentine	1·61
Petroleum	1·81

Another sample of petroleum gave as a mean of seven determinations 2·08, the highest and lowest values being 2·24 and 1·95 respectively.

The Author considers that his tests prove the formula to be correct. He points out that $\frac{F}{F'} = k^2$, when e is so small that it may be neglected.

The Author passes on to describe experiments made to determine whether there is any increase of specific inductive capacity with time—a phenomenon which he had had occasion to suspect existed in the case of sulphur. For this purpose he used samples of which he had previously ascertained the specific inductive capacity by a different method. Five plates of sulphur were tried, one being the identical plate experimented upon two years previously, carefully wiped and dried, the other plates being samples some three or four years old, remelted to adapt them to the new apparatus. Two plates of white paraffin and one of brown, all dating from the same period as the sulphur, were formed by remelting and tried, the brown paraffin, however, not having been tested before. Finally, a plate of ebonite two years old was tested after being carefully cleaned with glass-paper and dried. It was then kept in dry air for three months and the determination again made.

The Author gives a Table showing the results obtained, together with the thickness of the plates. He found that the value of k had nearly doubled in the case of the first plate of sulphur, and that the remelting had only partially destroyed this effect; indeed, after the second or third melting, the value only fell to rise again almost immediately. A sensible increase was also found in the case of ebonite, but paraffin hardly showed the effect at all except in one sample. The Author believes that the specific inductive capacity of a certain number of solid dielectrics, especially those the molecular structure of which may vary, is liable to increase sensibly with time, and he suggests that the discordant results obtained by different experimenters may be due in part to this.

C. H. W.

The Treatment of Persons suffering from Electric Shocks.

Issued by the French Ministry of Public Works.

(L'Électricien, 1895, p. 280.)

The French Ministry of Public Works has sent a circular letter to all prefects on the method of treatment advised for a person who accidentally makes contact with electric conductors. He explains that the Academy of Medicine had kindly drawn up some instructions as to the treatment to be adopted, and an electric commission had advised as to the technical precautions to be taken after the accident. The medical treatment recommended is the same in all cases of shock, but the precautionary steps to prevent further shock to either the injured man or the rescuers are different in the cases where alternating current and continuous currents respectively are in question. As soon as the contact between the injured man and the electric conductors is interrupted,

the medical treatment prescribed should be applied at once even if the victim appears to be dead.

In the case where the victim is still in contact with the conductors it is of the highest importance to proceed with caution in order that further injuries may not be caused to either the victim or his rescuers.

It is then absolutely dangerous to cut the electric conductors on continuous current systems, because the induced current caused by the interruption is likely to result in even more serious consequences to the injured man. With alternating currents there is not the same danger, and the severance of the wires is then advised. To make it safe to handle the injured man the wires must be cut on both sides of him. When the conductors are carried on posts placed in the public highways it is advised that the instructions referred to above should be firmly attached to a certain number of posts. The instructions must of course be those dealing with the aid to be given to persons injured by the electric systems on which the particular installation is carried out. In cases where posts carry wires for both continuous and alternating currents they should be arranged so that the less dangerous are the more accessible of the two. The Ministry adds that the instructions as to the treatment of persons who are suffering from electric shock have been drawn up specially as a guide to the engineers of bridges and highways responsible for electric mains in the public streets. Any assistance, however, which the prefects are able to give in making the instructions public will receive every commendation. This letter is followed by the instructions referred to, of which the following are abstracts:—

The medical treatment to be applied in the case where the victim appears to be dead consists of means for producing artificial respiration. The first method advised is that of pulling the tongue as far forward as possible, repeating the action about twenty times per minute for at least an hour. The second method which can be used concurrently with the first is similar to that employed on persons apparently drowned. The arms are moved back over the head and then pressed on the chest so as to induce movement in the lungs.

The technical instructions for disengaging the victim from the wires, and in certain cases for the severance of the wires themselves, are in full detail, which may be summed up in the statement that in handling either the victim or the wires, either the hands or the instrument used must be insulated.

R. W. W.

On the Probable Existence of a New Element in Terbine.

By — LECOQ DE BOISBAUDRAN.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 709.)

The Author publishes a note made by him in May, 1886, on the spectrum of a solution prepared from a sample of terbine then under examination. This particular specimen was an earth of a deep red-brown colour, the solution of which, in hydrochloric acid, gave a weak absorption spectrum composed entirely of the bands of dysprosium and a new band, which, according to the Author, does not belong to any known substance. The wave length of the centre of the new band is $\lambda = 487{\cdot}7$, corresponding to a micrometer reading of $140{\cdot}8$, and the width is between two and two and a half divisions of the micrometer scale. This position corresponds very nearly with one of the bands of erbium, but the other bands belonging to that element are absent. Owing to lack of material, the Author has been unable to proceed further with the research.

G. J. B.

New Properties of the Kathode Rays. By J. PERRIN.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxi., 1895, p. 1130.)

The kathode rays have been supposed by some to be due, like light, to vibrations of the ether, possibly of short wave-length. Others consider them to consist of matter charged negatively and travelling with great velocity. The latter hypothesis suggested to the Author the desirability of ascertaining by direct experiment whether the kathode rays are electrified or not. The following apparatus was employed :—

A vacuum-tube, furnished at one end with a metal disk serving as kathode, contained at the ether end, in place of the usual anode, a hollow metallic cylinder completely closed save for a small aperture in the centre of each end. This "protecting cylinder" enclosed a similar but smaller cylinder completely insulated from it, and supported by a platinum wire passing through the hole in the back of the protecting cylinder, and fused into the glass at the end of the vacuum-tube. Thus the kathode rays, passing through the aperture in the protecting cylinder, and through a corresponding aperture in the inner cylinder, would give up whatever charge they might possess to the latter, which would, as in Faraday's experiments, be completely protected from external electrical influence. The apparatus worked equally well with a Wimshurst machine or with an induction coil. The protecting cylinder being put to earth, the terminal of the inner cylinder was connected with an electrometer, and found to acquire a negative charge. But when the vacuum-tube was placed between the poles of an electro-magnet so as to deflect the kathode rays,

the cylinder inside the anode no longer became charged. It was found that the effect produced by the passage of a single spark from the induction coil was sufficient to charge a condenser of 600 C.G.S. units to a potential of 300 volts.

The law of the conservation of energy requires that a similar effect, in the opposite direction, should be produced at the kathode. On reversing the current this was found to be the case, the inner cylinder being now positively electrified, showing that while negative electricity is radiated from the kathode, positive electricity travels towards it. To determine whether this positive flux is in all respects similar to the negative, the Author modified the apparatus by introducing a second small diaphragm in the protecting cylinder, about half-way between the inner cylinder and the first aperture. Repeating the previous experiment, with the cylinder as anode, the kathode rays penetrated both diaphragms easily, causing strong divergence of the leaves of the electroscope, but on reversing the current, so as to make the protecting cylinder kathode, the electrification was much feebler.

With a more perfect vacuum the positive effect became greater, a condenser of 2,000 C.G.S. units being charged to a potential of 60 volts when the pressure was 3 micro-millimetres, whereas with a pressure of 20 micro-millimetres the potential reached was only 10 volts. In all cases the effect could be reduced to zero by deflecting the rays with an electro-magnet.

According to the Author's view, the molecules of residual gas around the kathode are separated into positive and negative ions, the latter acquiring a great velocity, and constituting the kathode rays. The positive ions move in the opposite direction, forming a diffused pencil, sensitive to the magnet.

G. J. B.

On the Pressure of Grain in Silos. By H. A. Janssen.

(Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 1045.)

The experiments the results of which are here recorded were undertaken by the Author for the purpose of ascertaining the proportionate pressure transmitted to the bottom and sides of deep hoppers or silos by a column of grain. This pressure cannot be treated on the same basis as fluids, on account of the friction between the grains; nor can it be calculated as for a solid body of earthwork.

It has long been recognised, with regard to the vertical pressure, that while up to a certain point this increases with the increasing depth of the column of grain, there is a point where the increase practically ceases, and the pressure remains constant. This maximum pressure is proportionate to the periphery or all-round measurement of the silo.

The Author carried out a number of experiments on the

contents of square wooden bins, in a series 8, 12, 16 and 24 inches square. These experimental bins were mounted on set-screws, and the bottom was formed by a movable board with lever to a platform weighing-machine, by which the bottom pressure could be accurately recorded. The following is a summary of the chief comparative results:—

		Dimensions of Bin.							
12 inches square.		12 inches square.		16 inches square.		24 inches square.		24 inches square.	
Weight of Contents.	Average Pressure on Bottom.	Weight.	Pressure.	Weight.	Pressure.	Weight.	Pressure.	Weight.	Pressure.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
37·0	25·0	39·0	25·0	80·0	60·0	210·0	160·0	280·0	200·0
73·4	33·0	73·0	35·0	132·0	80·0	270·0	240·0	580·0	300·0
88·8	38·0	94·0	39·0	170·0	90·0	490·0	280·0	860·0	340·0
130·0	42·0	139·4	42·0	276·4	110·0	600·0	310·0	1,000·0	360·0
180·0	45·0	180·0	44·0	384·0	120·0	760·0	340·0	1,080·0	370·0
360·0	46·0	360·0	46·0	768·0	126·0	1,080·0	370·0	1,780·0	380·0

These results are for wheat in wooden bins. With silos of different construction—*e.g.*, iron or cement surface—less side pressure would be taken up through surface friction, and the bottom pressure would accordingly be increased; as would also be the case with varying cohesion and attrition. With maize, for instance, the bottom pressure would be about 20 per cent. greater. It will be seen that, as might naturally be inferred, a small weight of grain in a large bin causes a higher rate of pressure than the same weight in a small bin; in other words, the leading factor in the grain-bulk is the height of the column in proportion to the horizontal dimensions of the silo. At the point of equilibrated bottom pressure, the friction between the grain and the sides of the silo is equal to the excess of the total weight of grain over the pressure on the bottom. In the last recorded experiment, for instance, the friction on the sides takes up 1,400 lbs. out of the 1,780 lbs., leaving 380 lbs. bottom pressure.

The Author states the subjoined formula for the side and bottom pressures respectively:—

(i) p = maximum pressure of grain against side of silo.
f = coefficient of friction between grain and material of which silo is constructed.
s = length of side (in square silo).
$d\,h$ = height of column of grain.
γ = specific weight of grain.

$$p \times f \times 4\,s\,d\,h = \gamma \times s^2 \times d\,h.$$

$$p = \frac{\gamma\,s}{4f}.$$

The coefficient f (determined by experiment) varies from 0·302 to 0·346. It may be noted that the side pressure decreases towards the angles, and is greatest at the centre of the side-length.

(ii) P = total pressure of grain on bottom of silo.
p = vertical pressure of grain per unit of surface.
p_1 = side pressure.
e = natural logarithmic basis.

$$K = \frac{p_1 f}{p}.$$

Other factors as in preceding formula.

$$p = \frac{s\gamma}{4K}\left(1 - e - 4K\frac{dh}{s}\right).$$

$$P = \frac{s^3\gamma}{4K}\left(1 - e - 4K\frac{dh}{s}\right).$$

Subjoined is an example of side pressure in a silo 10 feet square, containing wheat :—

Depth to which Filled.	Side Pressure.
Feet.	Lbs. per Square Foot.
5	150
10	252
15	326
20	367
26	404
33	424
40	443

P. W. B.

The Talc Quarries of Luzenac. By P. Pillez.

(Comptes Rendus de la Société de l'Industrie Minérale, 1895, p. 331.)

At Luzenac, in the upper valley of the Ariège, talc is quarried on an extensive scale in the granite of Saint Barthélemy, a mountain 7,700 feet high, and about 20 miles from the main chain of the Pyrenees.[1] The quarries, which are situated about 2 miles from the summit, and 5,900 feet above the sea, are opened in a bedded deposit, included between mica-schist below and Lower Silurian slates above, which has been followed for about 2,000 yards in a north-south direction, with a dip of about 60° to the east, the thickness varying from 160 feet to 1,000 feet, as does also the composition. Masses of limestone and granite, the latter often of considerable size, are frequently found included in the silicate of

[1] It is about 42 miles S.W. of Carcassonne and 55 miles S. of Toulouse.

magnesia, which also contains some alumina, as shown in the following analysis A, while B gives the composition of the talc of the Valley of Pignerolles, in Italy, which has a high reputation for quality:—

	A.	B.
Silica	61·85	60·60
Magnesia	34·52	35·30
Alumina	2·61	0·30
Ferric oxide	0·25	0·60
Lime	Trace	0·40
Combined water	0·60	Not determined
Alkalies and loss	0·17	2·80

The best rock is of a brilliant white colour, and feels greasy to the touch when ground to fine powder. The principal quarry, at Tremouin, is worked in the open, across the direction of the bed, forming two or three terraces, 50 feet high, the surface covering, 6 to 10 feet thick, having been first stripped. The stuff broken is carried by a level, in the bottom of the quarry, driven in the foot-wall of the vein, to the valley of Axiat, whence it is hauled in bullock wagons about 12 miles to the works at Luzenac, where a water-power of 90 HP. is obtained from the Ariège. The mechanical preparation includes sizing by sieves, drying in a rotating-cylinder furnace, breaking, grinding and sifting. The grinding is done in ball-mills, which rarely require to be stopped for repairs. Nearly the whole of the product is converted into powder; only a small part being made into pencils for marking out work on metal or sold in the lump form. The consumption extends to almost all parts of Europe and America. The principal applications are in soap-making and perfumery, paper-making and weaving. It also forms an ingredient in wagon grease, and is used as an insulator for electric conductors. A new preparation called cupro-steatite, made by mixing talc and sulphate of copper, is now being tried with success as an insecticide in vineyards.

H. B.

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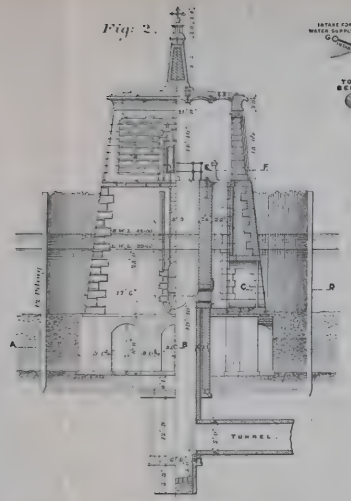

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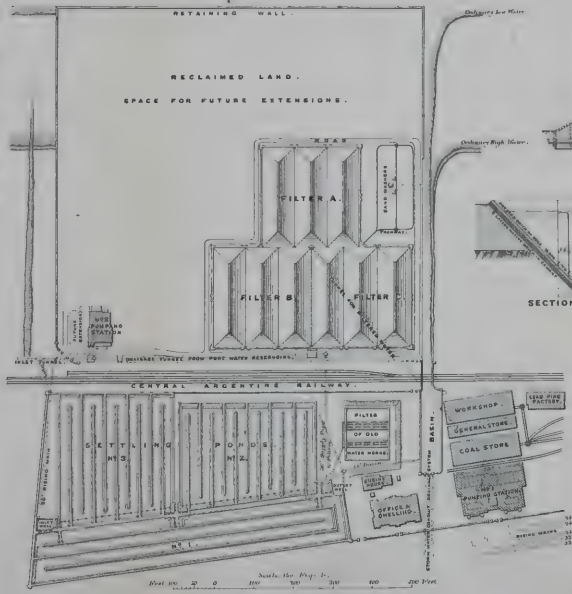

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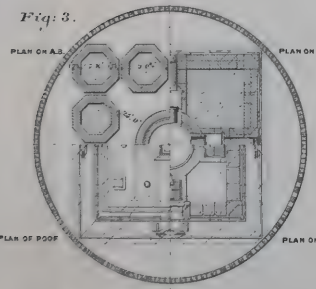

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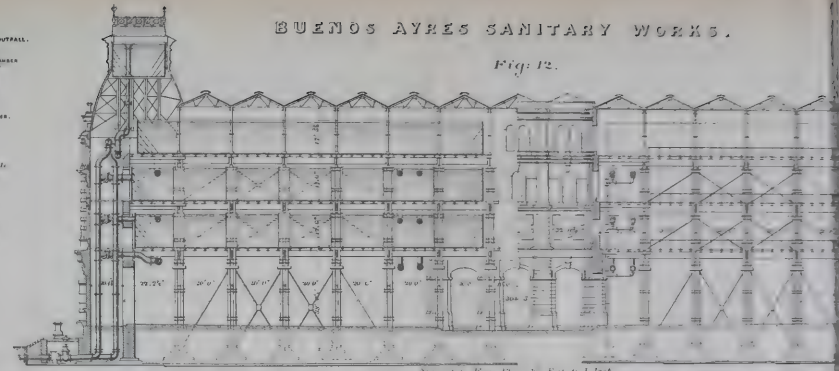

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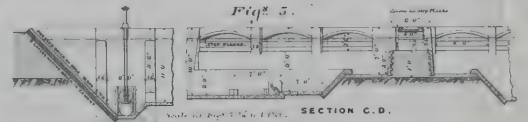

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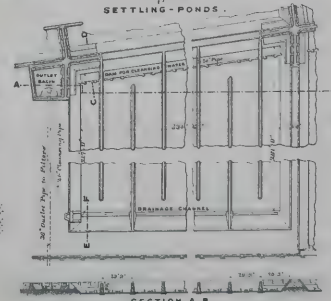

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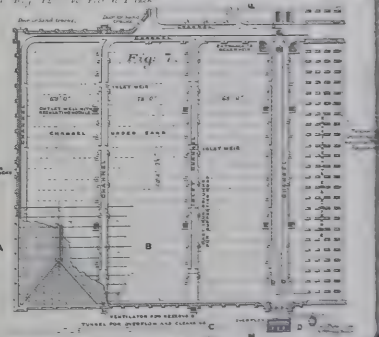

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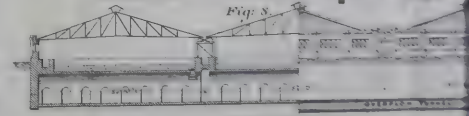

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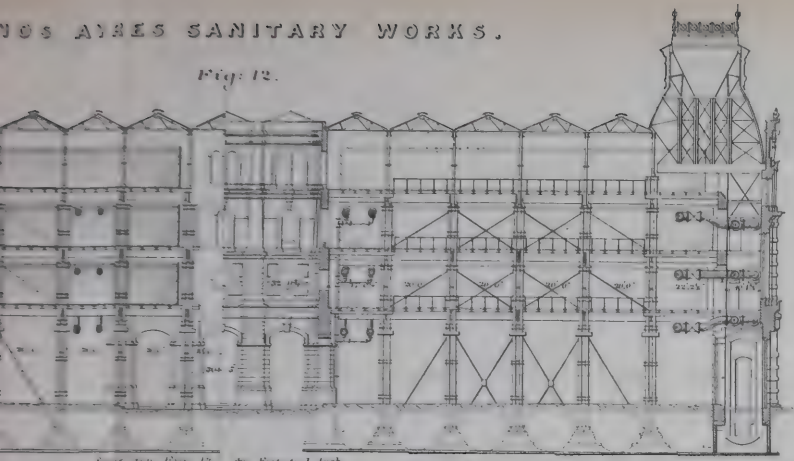

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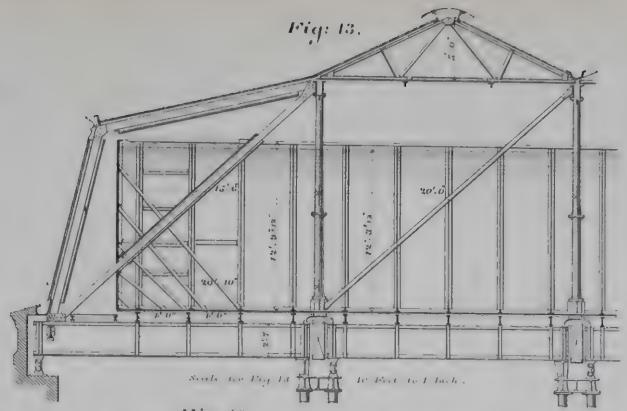

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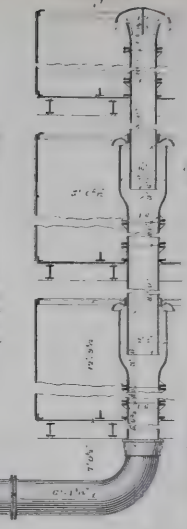

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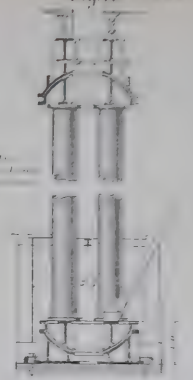

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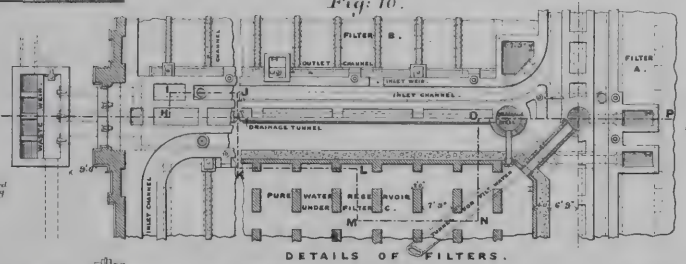

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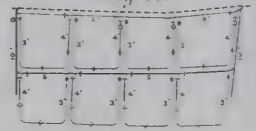

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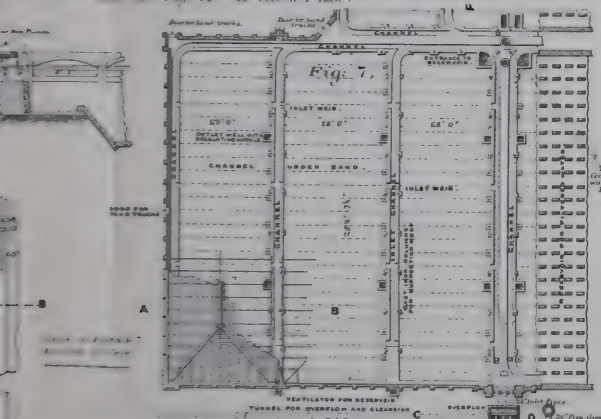

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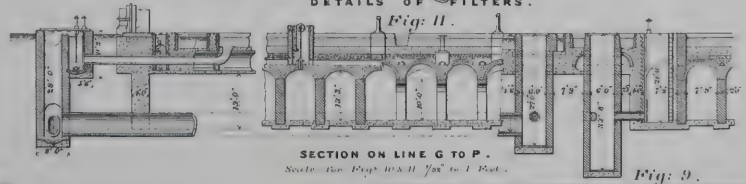

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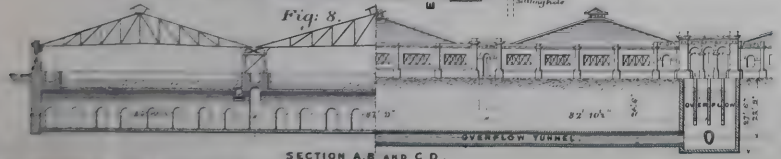
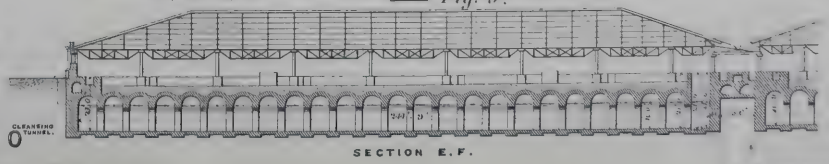


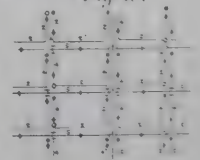
SECTION A.B AND C.D.

Fig: 9.



SECTION E.F.

Fig: 18.



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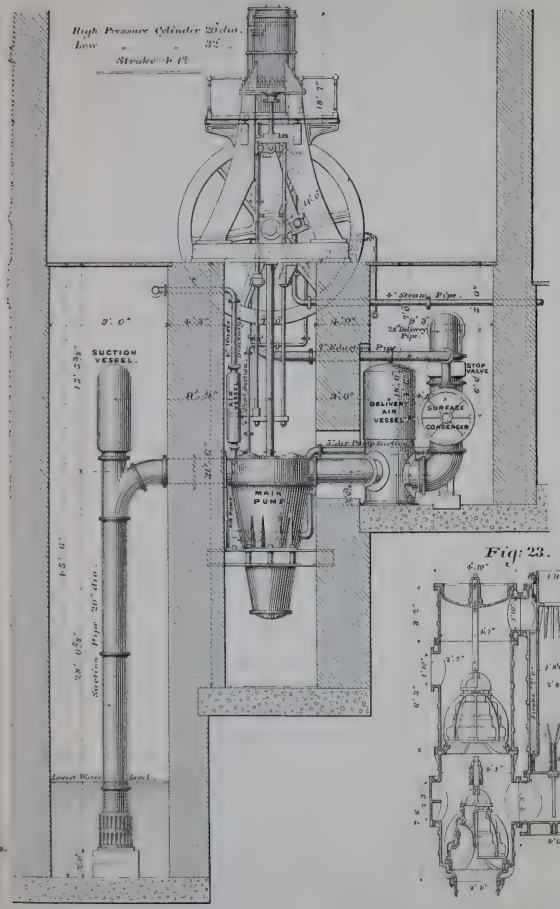

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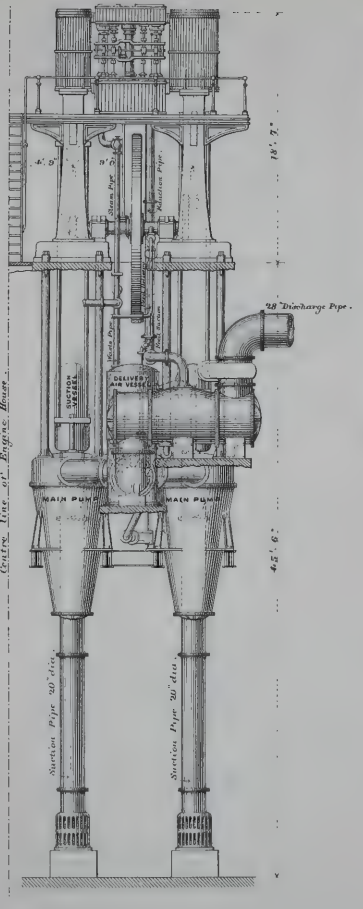

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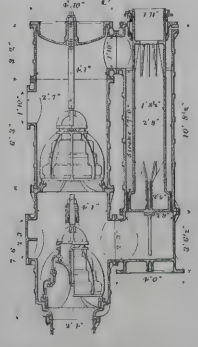


Scale for Fig: 23.

Inches 6 5 4 3 2 1 0 — 5 — 10 Feet.

Fig: 21.

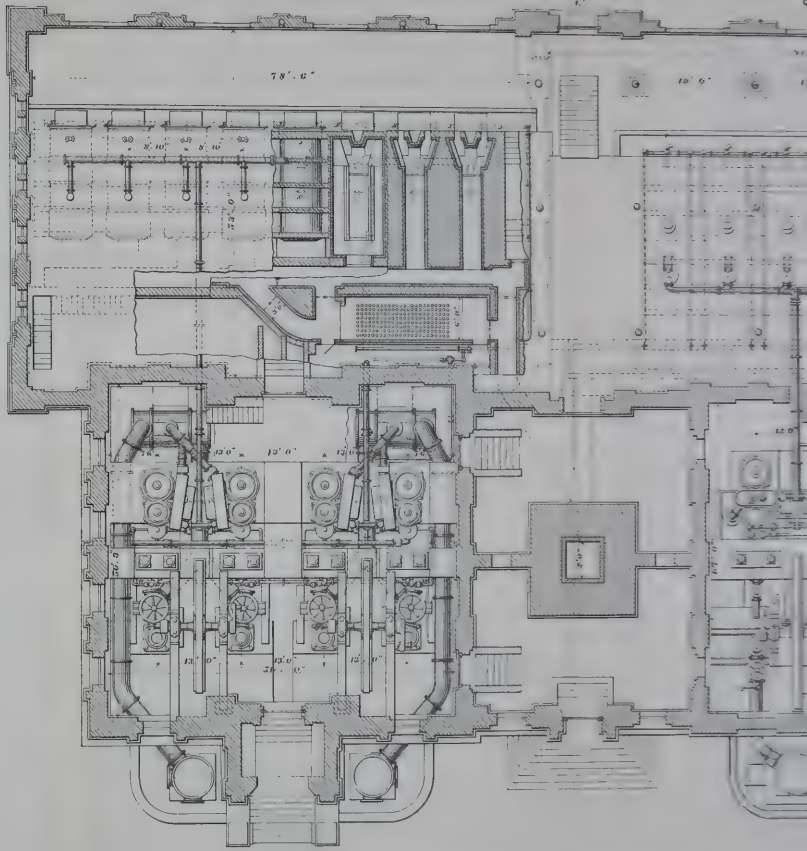
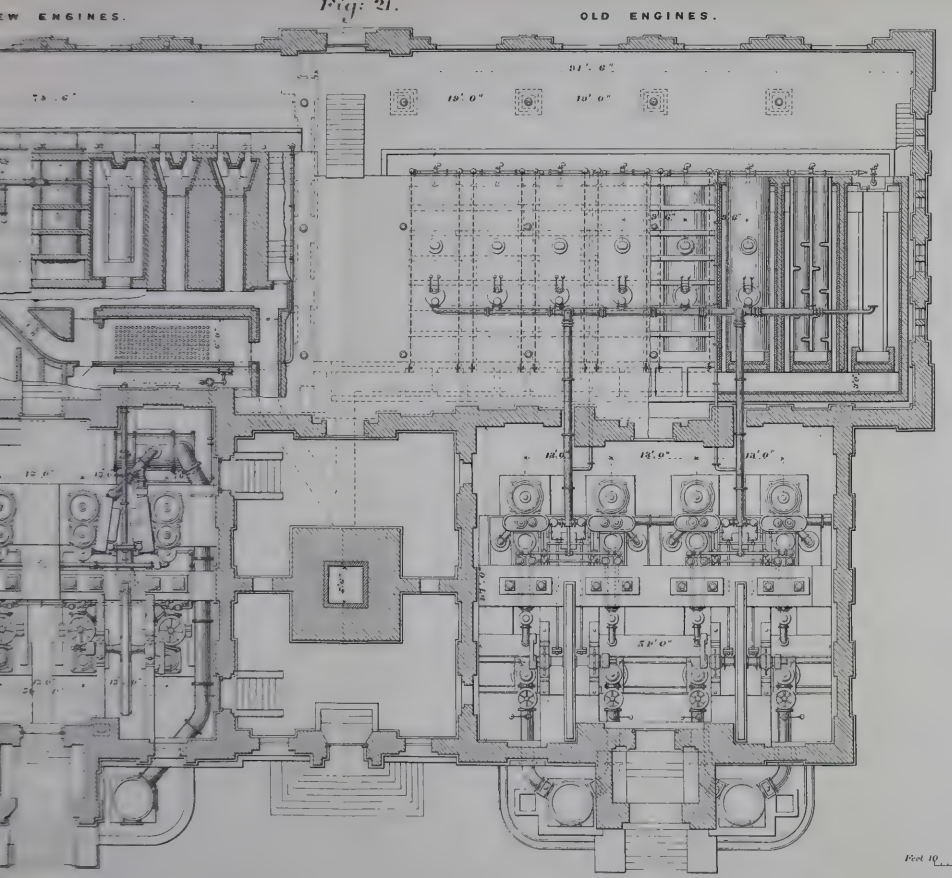


Fig: 21.



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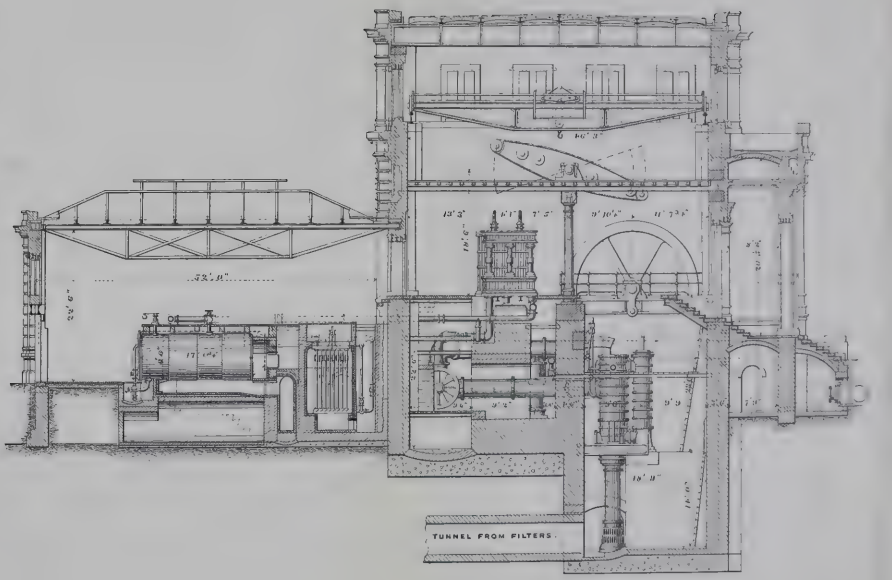


Scale for Figs. 19 & 21

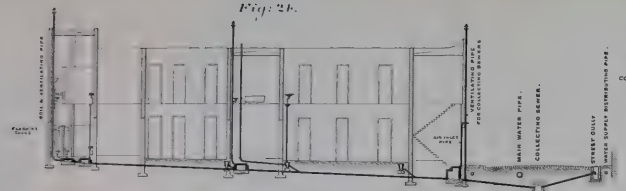
Feet 10 5 0 10 20 30 Feet.

Scale for Figs. 21 & 22.

Feet 10 5 0 10 20 30 40 50 100 Feet.

BUENOS AYRES SANITARY

Fig: 24.



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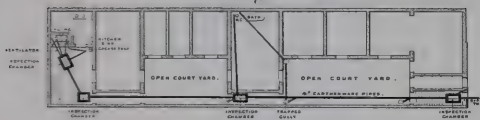

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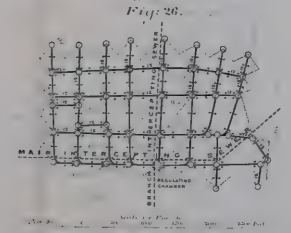
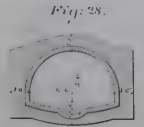


Fig: 27.

Fig: 28.



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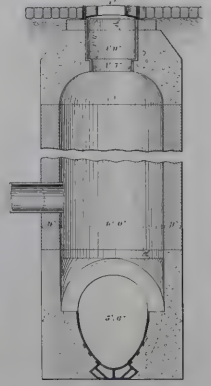

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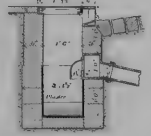

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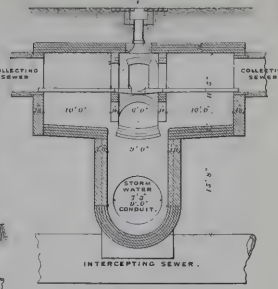

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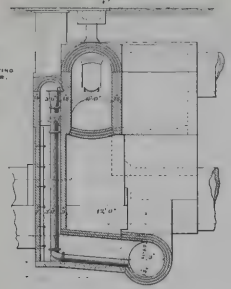

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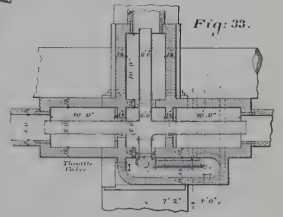

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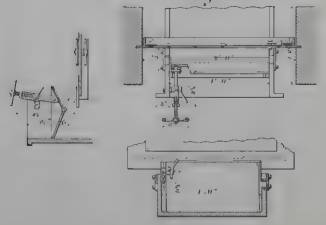

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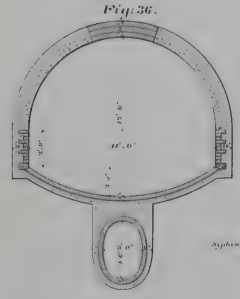

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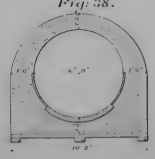

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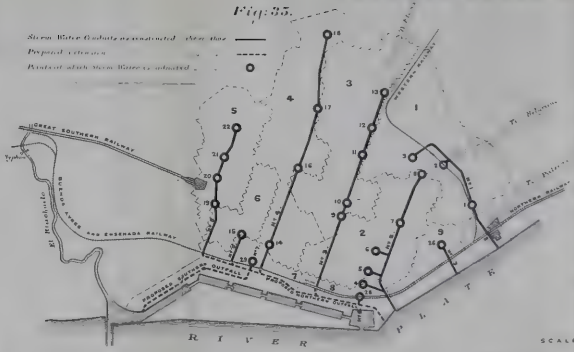

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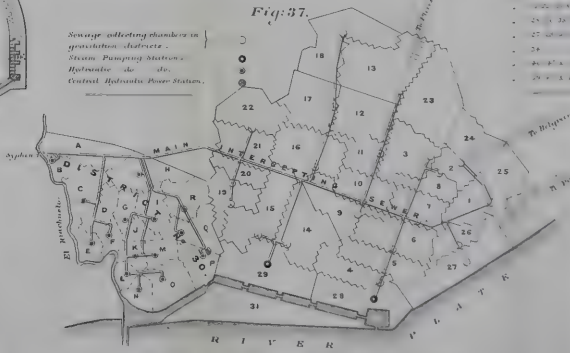

Fig: 40.

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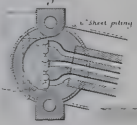

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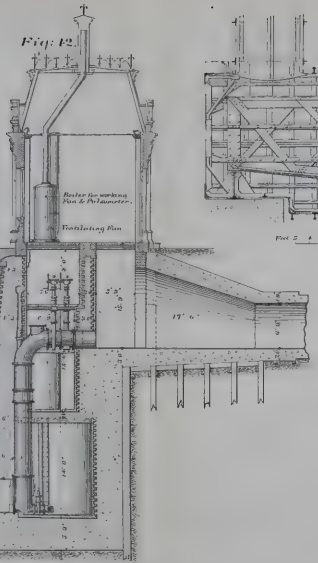

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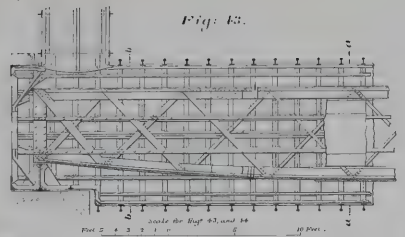

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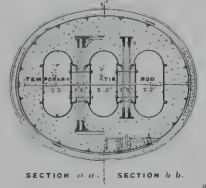
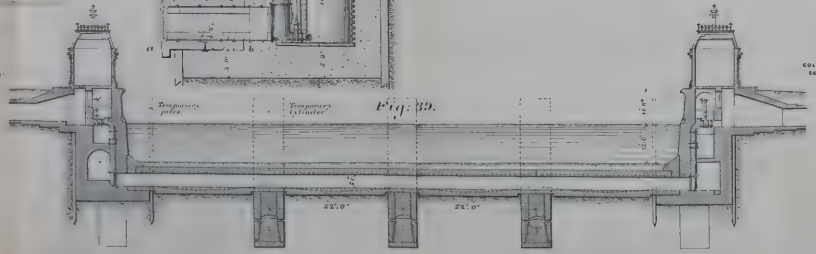


SECTION a a. SECTION b b.

Fig: 39.



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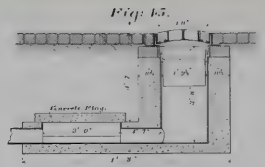
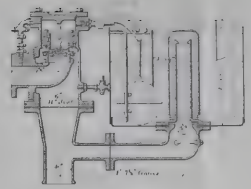


Fig: 46.

Fig: 47.



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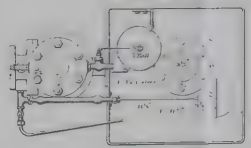

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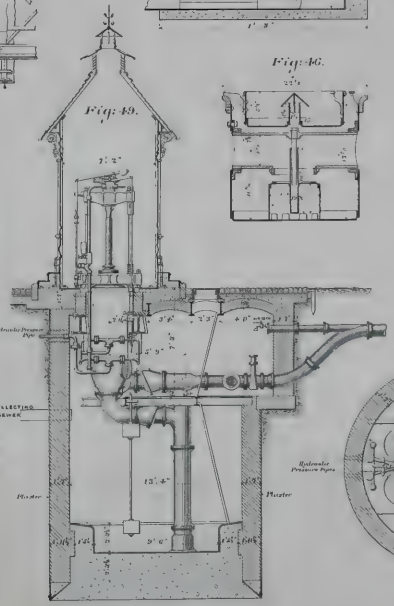

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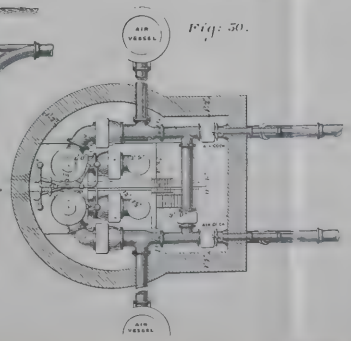
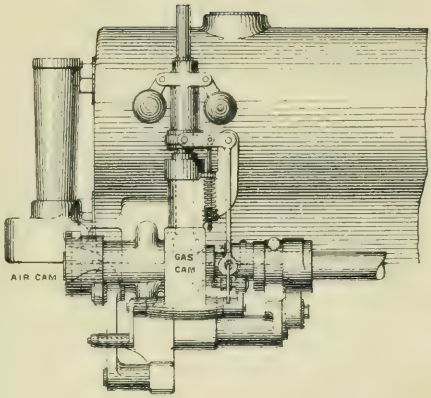


Fig: 51

SCALES



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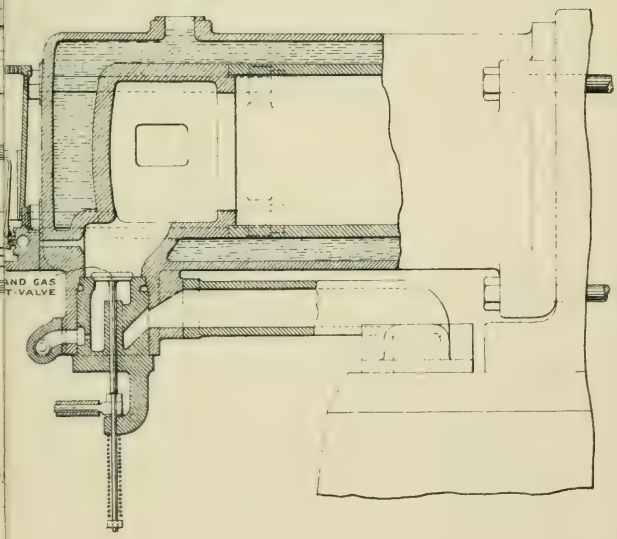
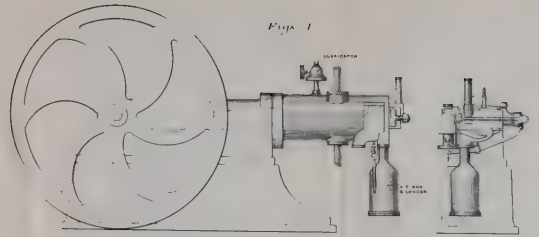
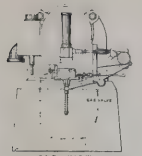
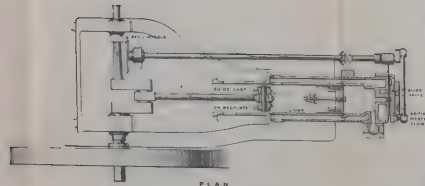


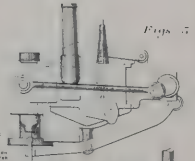
Figs 1

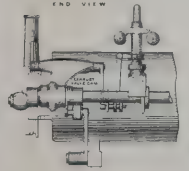


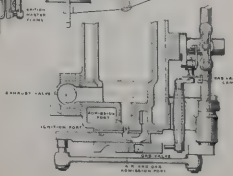


Figs 5

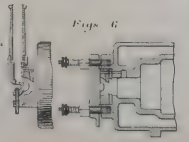






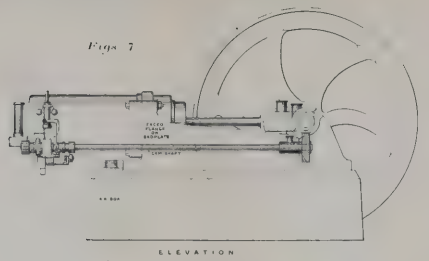


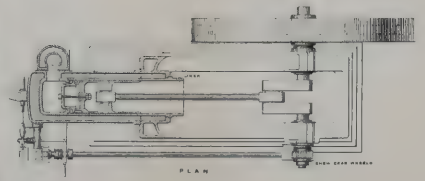
Figs 6



6 HP CROSSLEY ENGINE No 4683 1892

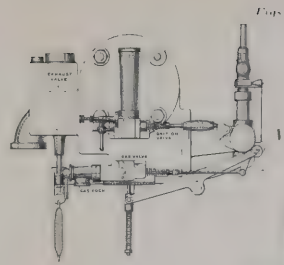
Figs 7





9 HP CROSSLEY ENGINE No 19772. 1892

Figs 8



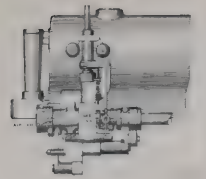
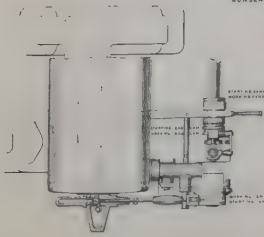
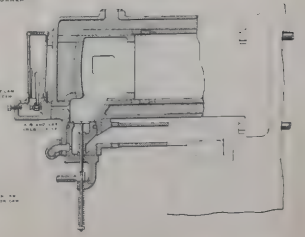


Fig 9





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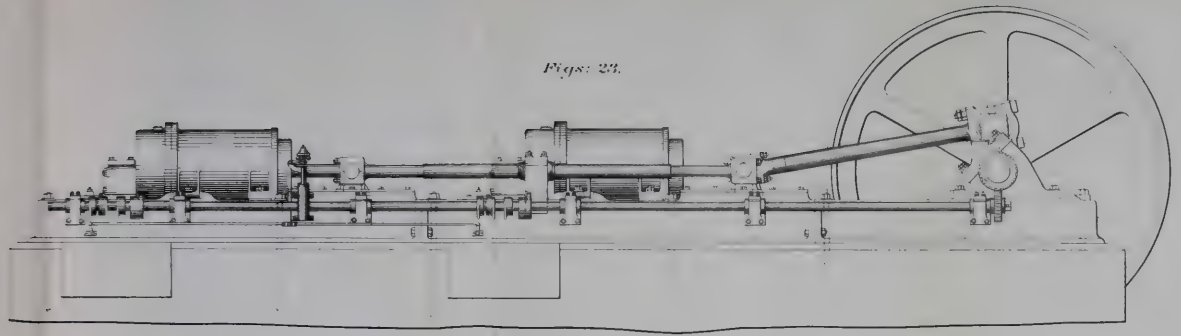
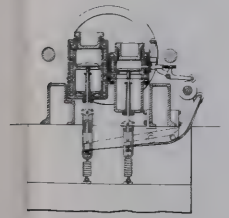
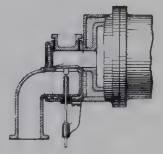
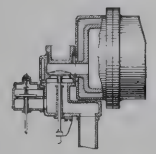


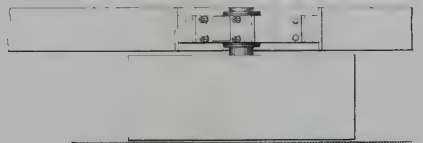
ELEVATION

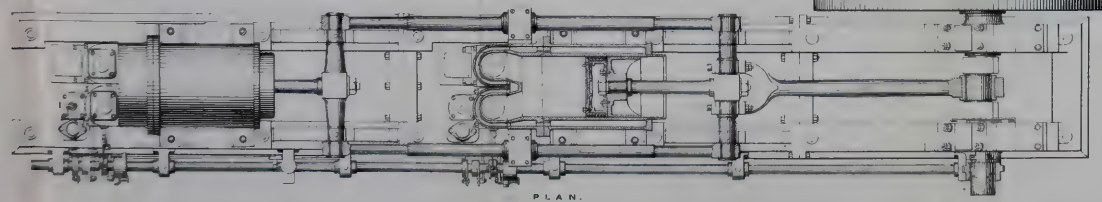


END VIEW.





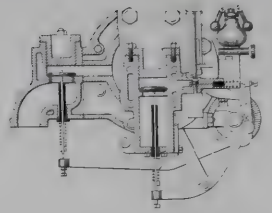


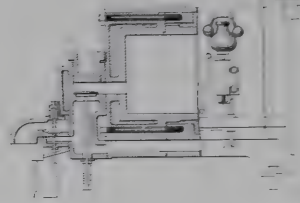


PLAN.

400 H.P. ANDREW - OTTO ENGINE.

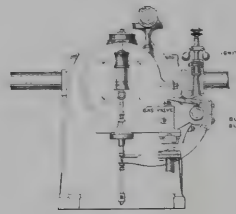
Figs: 24.



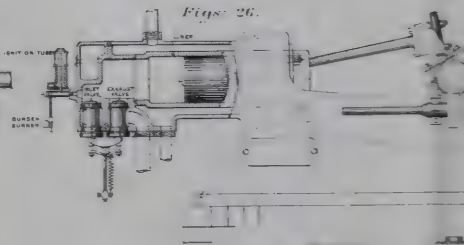


ANDREW - OTTO ENGINE.

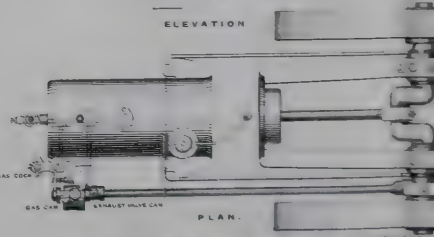
Figs: 26.



END VIEW.

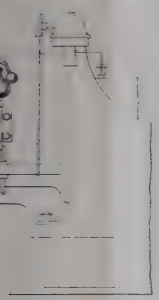


ELEVATION



PLAN.

12 H.P BARKER - OTTO ENGINE.



OTTO ENGINE.

Fig: 25

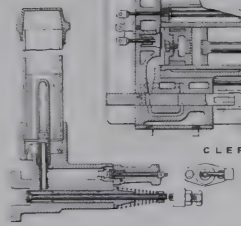
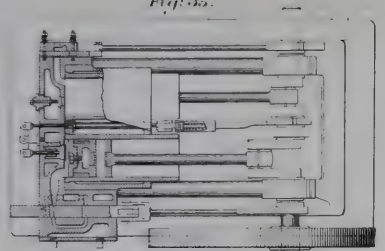
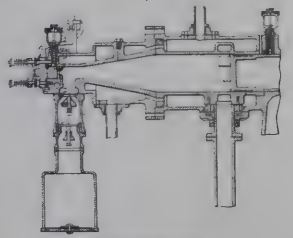


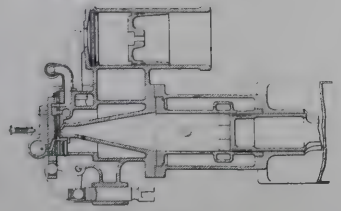
Fig: 35.



CLERK ENGINE 1878.

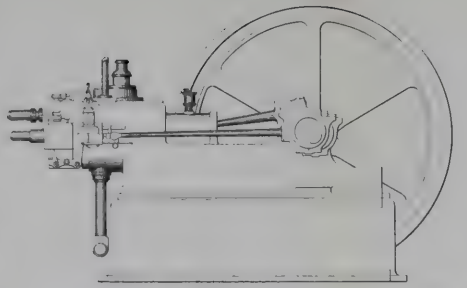
Figs: 36.



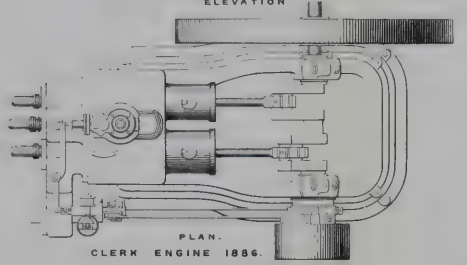


CLERK ENGINE 1881.

Figs: 38.

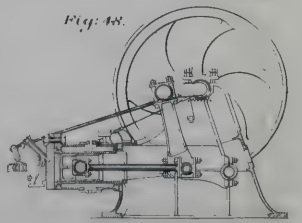


ELEVATION



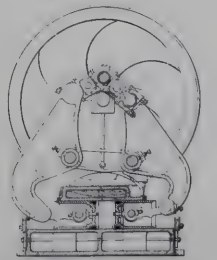
PLAN.
CLERK ENGINE 1886.

Fig: 48.



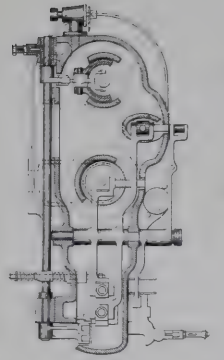
ATKINSON CYCLE ENGINE.

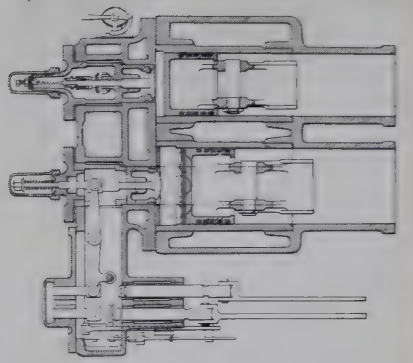
Fig: 46.



ATKINSON DIFFERENTIAL ENGINE.

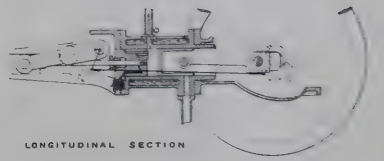
Figs: 39.



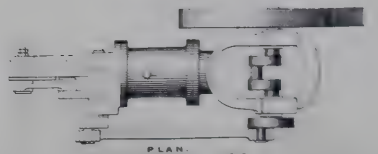


CLERK ENGINE 1886

Figs: 44.



LONGITUDINAL SECTION

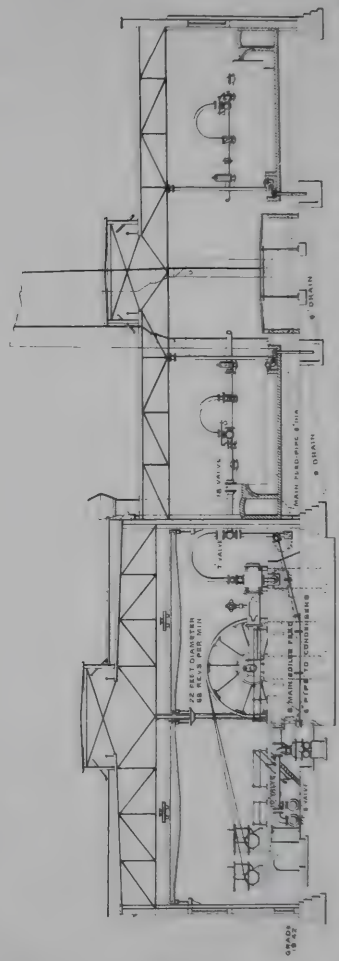


PLAN.
CLERK ENGINE 1889.

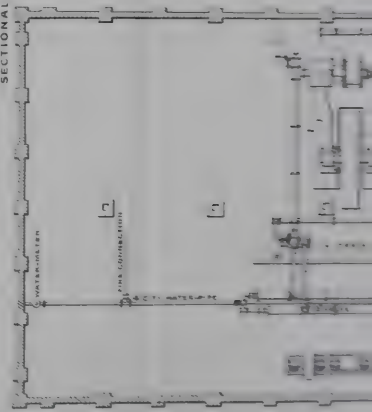
Fig 1.

MAP OF MONTREAL

MONTREAL ELECTRIC STREET-RAILWA



SECTIONAL ELEVATION ON A.A.



Figs: 4.

NOTE.

Engines H.P.Cyl. 24 ins. dia. L.P.Cyl. 48 ins. dia. 48 ins. stroke.
Condensers Steam Cyl. 12 ins. dia. Water Cyl. 15 ins. dia. 10 ins. stroke.
Boilers 7 feet dia. 28 feet long.
Chimney 8 feet dia. inside. Height 180 feet above Fire Grate.
Boiler Feed Pumps Steam Cyl. 12 ins. dia. Ram 7 ins. dia. 10 ins. stroke.
Green Economizer. 800 pipes.
Generators 2. 200 KW. B. Belgers. 6. 300. KW. Mulle. Belgers.
Steam Pressure. 125 lbs. per square inch.

Scale for Figs. 4. 32 Feet to 1 Inch.

Feet 0 5 10 20 30 40 50 60 70 Feet

SECTIONAL ELEVATION ON A.A.

PLAN.

Figs: 5.

Scale for Figs. 5.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

FIRST FLOOR.

GROUND FLOOR.

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1
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v. 124
pt. 2

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